The fishery resources of Pacific island countries

Part 1. Deep-water shrimps

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ISBN 92-5-102430-8

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PREPARATION OF THIS REPORT

This document on deep-water shrimps represents the first contribution to the review of the fishery resources of Pacific island countries undertaken by the FAO Fisheries Department.

Fishery resources are among the most important national assets of many small island countries, but are necessarily limited by the size of continental shelf. This paper aims at documenting the potential for development of such underutilized resources, particularly in deep waters, and it covers biology, method of fishing and marketing.

ACKNOWLEDGEMENT

Field work in Pacific islands was carried out while the author was at the Institute of Marine Resources of the University of the South Pacific, Fiji. Thanks are due to the Director of this Institute, Dr. Uday Raj.

Information, both published and unpublished, was kindly provided by K. Simonds, R. Gooding, N. Iwasaki, S. Ralston, N. Quinn, R. Methot and R. Moffit. The chapter dealing with the marketing aspects was prepared jointly with S. van Eys, from INFOFISH.

The manuscript was improved by comments from A. Carver, R. Ruello, I. Cartwright, N. Ruello, F. Chopin, N. Iwasaki an R. Moffit.

Distribution

FAO Fisheries Department
FAO Regional Fisheries Officer
Author
Pacific Island Countries

For bibliographic purposes, this document should be cited as follows:

King, M.G., 1986 The fishery resources of Pacific island countries. Part 1. Deep-water shrimps. FAO Fish.Tech.Pap.,(272.1): 45 p.

ABSTRACT

Deep-water caridean shrimps have been found in many tropical Pacific Islands by setting baited traps in depths down to over 800 m. There has been some interest in the exploitation of these shrimps, particularly those belonging to the genus _Heterocarpus_. This report summarizes the available information on the species found, their distribution, biology and commercial potential in Pacific Island countries.

CONTENTS

		Page
1.	Introduction	1-2
2.	Traps	2-7
3.	Bait	7-8
4.	Fishing methods	8-10
5.	Species found	10-17
6.	Distribution by depth	18-23
7.	Biological aspects	24-31
8.	Potential yields	31-36
9.	Commercial operations	36-38
10.	Handling and marketing	39-41
11.	References and bibliography	42-45

1. INTRODUCTION

Natantian decapod crustaceans (shrimps and prawns) form the basis of valuable trawl fisheries in many areas of the world. Penaeid shrimps, in particular, are trawled in the shallow coastal waters of tropical and subtropical countries and are found in several Pacific islands.

Trawling and other "active" methods of fishing, however, are often unsuitable in tropical islands due to the presence of extensive coral formation in shallow water, and the great depths beyond the reefs. On the other hand "passive" methods of fishing, including gill nets, set lines and traps, are widely used in tropical countries including the islands of the Pacific Ocean. These methods are also favoured because of the smaller amounts of fuel used compared with active fishing methods. A recent development has been the interest shown in the exploitation of deep-water shrimps by setting baited traps (King, 1981b).

Small numbers of deep-water caridean shrimps were found during trawling surveys in Hawaiian waters during 1967 and 1968 (Struhsaker and Yoshida, 1975) and these species were later found to be susceptible to trapping (Clarke, 1972; Struhsaker and Aasted, 1974). Deep-water shrimps were subsequently found in the northern Pacific islands of Guam (Wilder, 1977) and the Northern Marianas (Moffitt, 1983). The most extensive surveys have been carried out in Hawaii and the Marianas where traps have been set in many different locations (Oishi, 1983; Ralston, in prep.; Dailey and Ralston, in prep.; Moffit and Polovina, in prep.).

South of the equator, deep-water shrimps have been found in Fiji (Brown and King, 1979; King, 1984) and New Caledonia (Intès, 1978). The Fijian surveys are notable, in that they were carried out over an extended time period in one location, beyond the barrier coral reef near Suva.

A trapping survey by the research vessel "Tainui" in Tahiti during 1978 (Anon., 1979a) obtained deep-water shrimps in numbers too small to encourage further work (P. Hatt, pers.comm., 1980). The survey was, however, brief and did not extend to depths beyond 580 m.

Encouraging catches of shrimps were made during a preliminary deep-water trapping survey in Vanuatu then the New Hebrides, during 1980 (King, 1981). Further surveys were conducted during 1981 and 1982 (De Reviers et al; 1982).

Specimens of caridean shrimps were taken in Western Samoan waters by the French Research Vessel "Coriolis" (Anon., 1977) and during a fisheries resource survey in 1980 (King, 1980; King, 1984). In 1981, a preliminary survey was completed in Tonga (King, 1981a; King, 1984). The South Pacific Commission (Noumea, New Caledonia) funded a consultancy in 1982 to initiate a deep-water shrimp assessment programme for the Fisheries Division of the Department of Primary Industry in Papua New Guinea; during a demonstration in the use of traps, small number of caridean shrimps were caught near Port Moresby (King, 1982). The University of Technology in Papua New Guinea has students involved in a deep-water trapping survey near Lae (N. Guinn, pers. comm., 1985).

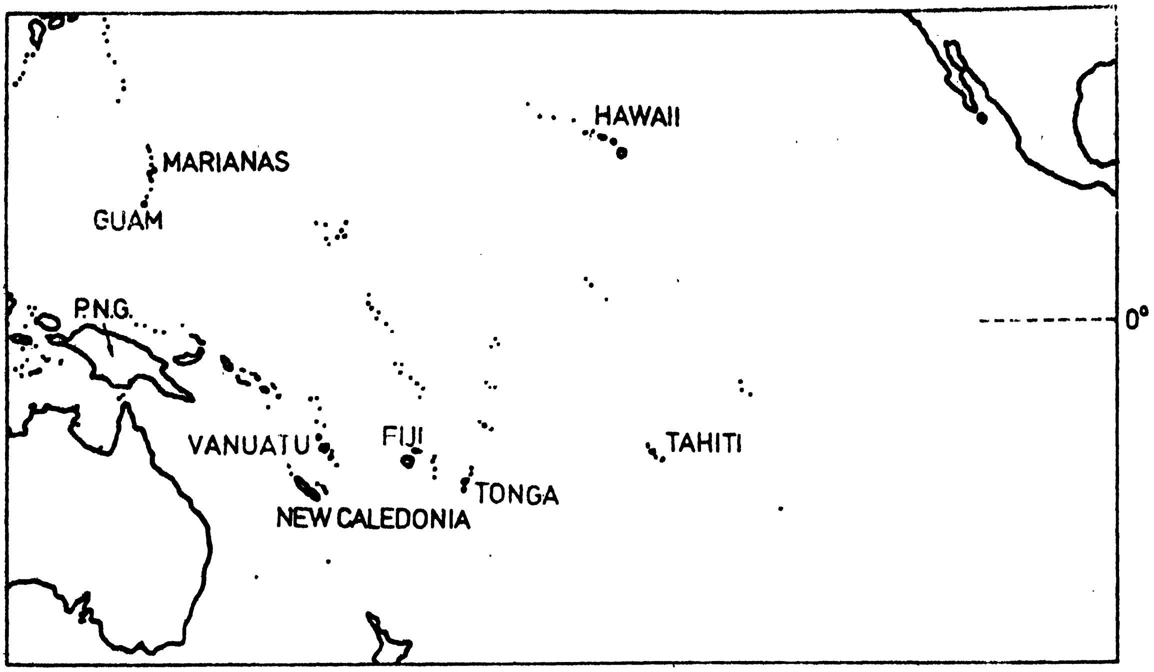


Figure 1: The Pacific Ocean, showing island countries referred to in the text.

Although at least sixteen species of deep-water carideans have been found, and many of these are widely distributed in Pacific islands, development of the resource has been limited. Shrimps belonging to the family Pandalidea, particularly the larger species of the genus Heterocarpus (nylon shrimps), are generally regarded as having the best commercial potential. H. reedi has been the basis of a trawl fishery in Chile, where catches reached over 9000 t. per year in the 1970's (Weinborn, 1982). The greatest commercial use of deep-water shrimp resources in Pacific Islands has been in Hawaii, no doubt because of its large cosmopolitan population and access to more sophisticated local and overseas markets.

This report reviews the fishing methods used and the species of deep-water caridean shrimps caught in Pacific islands. Marketing aspects and the commercial potential of the resource are also discussed.

2. TRAPS

Traps have been used traditionally in many crustacean fisheries such as those for crabs, lobsters and shrimps. Trap designs used in such fisheries have generally evolved through use by fishermen rather than through experiments by scientists; only in a few cases have such traps been developed or improved by controlled experiments. In working on a potentially new resource such as tropical deep-water shrimps, however, there has been no historical experience of commercial catching methods to draw upon.

Several different types of traps have been used to catch deep-water shrimps in Pacific Islands, but all are based on the principal that shrimps, attracted by bait, enter cone-shaped entrances to the trap and find it difficult to escape. Trap frames are usually made from steel reinforcing rod and covered with bird or chicken-wire mesh; both of these items are usually available in Pacific Islands. A hinged gate is included to allow the removal of the catch and the placement of bait. The parts of a general shrimp trap are shown in Figure 2.

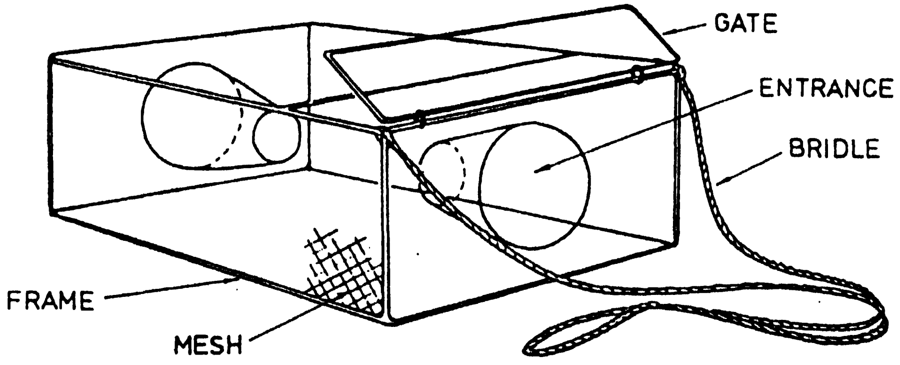


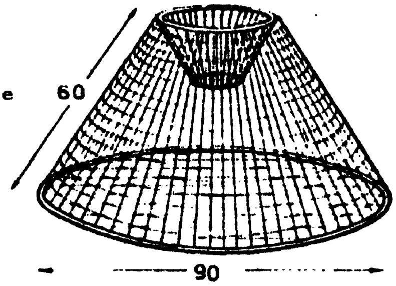
Figure 2: A shrimp trap illustrating the parts referred to in the text, Bait is hung from the center of the top of the trap.

Traps in the shape of a hemisphere with a flat circular base and a single entrance in the top have been used traditionally to catch pandalid shrimps (Pandalus species) in Japan (Suisan Hokkaido Kyokai, 1981). Similar top-entrance traps in the shape of a four-sided, truncated cone were tested in trials in Fiji (King, 1983) and were found to be less efficient in catching Heterocarpus species than box-shaped traps with side entrances. In a survey in New Caledonia, however, a conical trap (Figure 3A) was preferred on the basis of convenience (Intès, 1978). Conically shaped traps may be easier to stack on vessels with limited deck space.

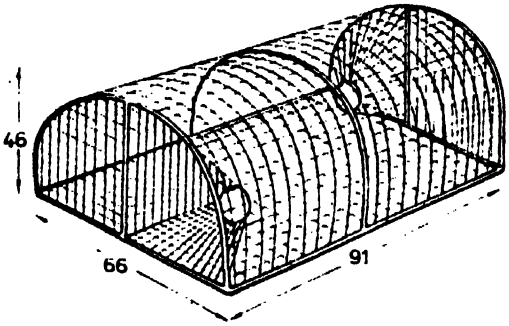
A semi-cylindrical trap with a rectangular base and conical entrances worked into quadrants at each end (Figure 3B) has been developed for use as a standard deep-water shrimp trap by the Honolulu Laboratory of the National Marine Fisheries Service in Hawaii (Gooding, 1984; Ralston, in prep.). Rectangular box traps with ramp-shaped entrances in each end (Figure 3C) were used in a deep-water survey in Vanuatu (King, 1981).

A range of trap types, including conical, semi-cylindrical and box traps, was tested during surveys in Fiji (King, 1983). Simple box traps were statistically the most efficient of those tested and there was no statistical difference between the catch-rates of box traps with two entrances (on opposite sides) and those with entrances in all four sides (Figure 3D). Some caution should be exercised, however, in accepting the results of such trials as an indication of the relative efficiency of different shapes of traps. Traps efficiency is likely to depend on more subtle design variations than the gross differences tested. The shape and position of the trap entrance, for example, may be critical. One minor change to the standard box traps used in Fiji was to move the trap entrances so that they did not exactly oppose each other (Figure 3D). It was thought that this change might reduce shrimp escapement.

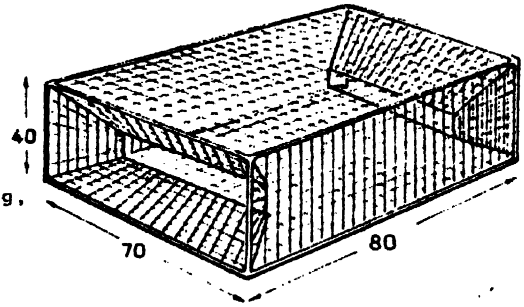
A. CONICAL TRAP: With a single entrance at the top (outer diameter 30cm). Used in surveys in New Caledonia (Intès, 1978).



B. SEMI-CYLINDRICAL TRAP: With one quadrant-shaped entrance at each end (inner diameter 8 to 10cm). Used in the Hawaiian Islands (Gooding, 1984) and the Mariana Achipelago (Ralston, in prep.).



C. RECTANGULAR BOX TRAP: With a ramp entrance at each end (inner dimensions 8 x 25cm). A similar trap design but with circular inner entrances was used in a survey in Vanuatu (King, 1981a).



D. SQUARE BOX TRAP: With a conical entrance (inner diameter 10 to 12cm) in all four or two opposing sides. Used in surveys in Fiji (King, 1983) and Tonga (King, 1981b).

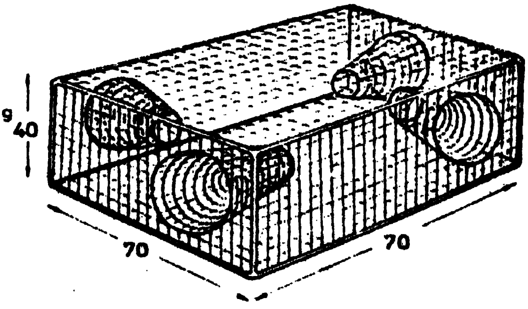


Figure 3: Small volume traps (less than 0.3 m^3) used to catch deep-water caridean shrimps in tropical Pacific Island countries. Trap dimensions are given in centimetres.

The traps described above and illustrated in Figure 3 generally have an internal volume of between 0.2 m^3 and 0.3 m^3 (less than 1 m. in any linear dimension). In the commercial fishery for deep-water shrimps in Hawaii there has been a trend towards the use of much large box-shaped traps (approximately 2.4 m x 3.0 m x 3.0 m) covered with 2.5 cm mesh. These large volume traps are reported to be capable of catching at least five times more shrimps than small traps (Methot, 1984). A large commercial trap of a pyramidal shape (1.5 m x 1.5 m x 1.5 m) was used in an experiment in the Marianas (Ralston, in prep.) and was found to be more efficient than the standard Honolulu Laboratory trap by a ratio of 5.76:1.

In an effort to increase the number of traps that can be safely carried by a small vessel, there has been some interest in collapsible traps. The traps may be covered with twine netting and have hinged sides which fold down onto the base. In spite of their use in some Japanese fisheries, collapsible traps are generally considered too fragile for continuous commercial use.

No information is available on the loss of shrimps through the trap entrances while the trap is on the sea-floor although once the bait is exhausted the loss of shrimps may be high. In traps with chicken-wire conical entrances the simple measure of folding a lip on the inner entrance of the cone (Figure 4) appeared to result in higher catches during the surveys in Fiji. Although no statistical analyses are available to support this claim, it may be that the curved lip directs shrimps moving around the inside perimeter of the trap away from the trap opening.

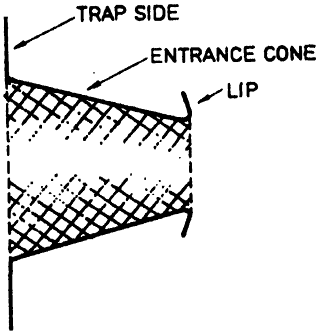


Figure 4: A side view of a trap entrance cone made from chicken-wire with a folded inner lip.

The loss of shrimps from entrances while the trap is being hauled up to the surface may be considerable, particularly when a low-powered winch is used and hauling speed is slow. Traps used to catch Pandalus jordani in Japan showed an increase of 50 percent in catch rates when trap entrances were sealed with a trap-door during hauling (Koike et al., 1981). In these traps, the trap-doors were held away from the entrances by elastic cords while the traps were on the sea-floor. As the traps were hauled in, tension on the hauling-line closed the trap-doors (Figure 5). With traps set in strong currents; however, there is the danger that pressure on the lines may close the trap-doors while the traps are on the sea-floor.

There has been some history of using traps covered with hessian sacking or burlap in Hawaiian waters. Struhsaker and Aasted (1974) suggested that "covered" traps were more efficient in catching deep-water shrimp than uncovered ones. Reasons for this could include the cover functioning either to concentrate substances from the bait at the entrances to the trap, or to provide additional shelter for the shrimps (i.e. to act as a "habitat" trap). In Hawaiian waters covered traps were claimed to be from 2.5 to 10 times more effective than uncovered traps (Struhsaker and Aasted, 1974) although data were not presented to support this claim. During trials in Vanuatu (King, 1981) and Fiji (King, 1983); however, no significant differences were found between the catch rates of covered and uncovered traps. The crew of the commercial fishing vessel "Hawaiian Princess" trapping in the Northwestern Hawaiian Islands also noted no difference between the efficiency of covered and uncovered traps (Oishi, 1983).

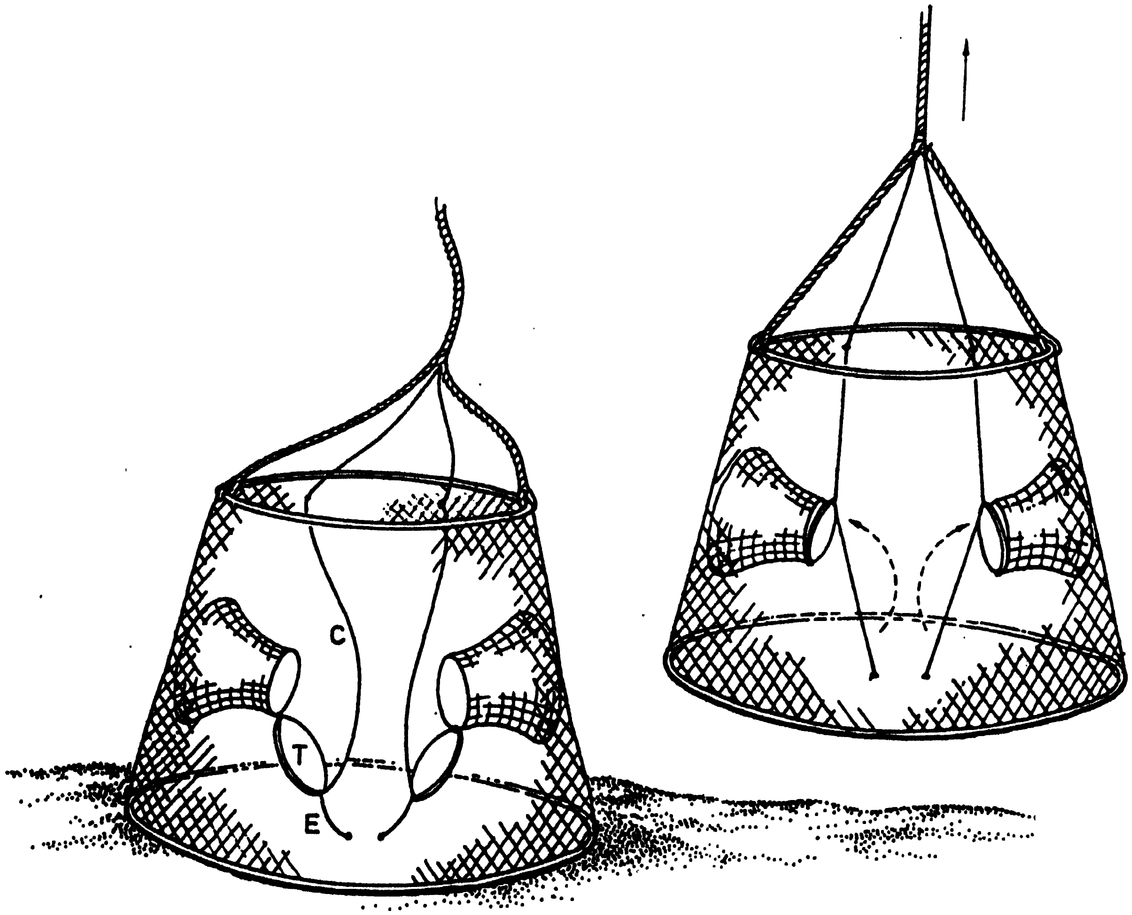


Figure 5: A shrimp trap with closing trap-doors at the inner openings of entrance cones; used experimentally to catch *borealis* in Japan (from Koike *et al.*) -LEFT: When the trap is in position on the sea-floor the trap-door (T) is held away from the opening by an elastic cord (E). -RIGHT: When the trap is hawled in, pressure on the connecting line (C) closes the trap-door.

As results from surveys provide contradictory evidence on the relative performance of covered and uncovered traps, this appears to be an important area for future gear-testing trials. An evaluation of economic aspects of using covered traps needs to take account of the higher costs in producing such traps and the much greater water resistance caused by the addition of covers. A small winch capable of hauling a maximum of 12 uncovered traps on a single string may only be capable of hauling less than half this number of covered ones.

Although there is little information available on the selectivity of traps for *Heterocarpus* species, it is likely that the use of large mesh sizes in uncovered traps allows the escape of smaller individuals from the catch. A mesh selectivity curve for *Heterocarpus sibogae* caught in traps covered with standard chicken-wire of hexagonal shape (measuring 18 mm across the greatest dimension) is shown in Figure 6 (data from King, 1983). The size at which 50 percent of individuals are retained by chicken-wire mesh was approximately 16 mm carapace length for both H. sibogae and H. laevigatus, and 14 mm for H. gibbosus. Traps covered with hessian are also likely to be selective if part of the trap is left uncovered, or if escape gaps are included in the trap design.

Mesh selectivity can be a useful management tool in commercial trap fisheries. Regulations for a legal minimum mesh size may be used to reduce the catch of smaller sizes of shrimps which have a low market value. However, as natural mortality rates of Heterocarpus species appear to be high this may not provide a greater yield to the fishery (see Section 8).

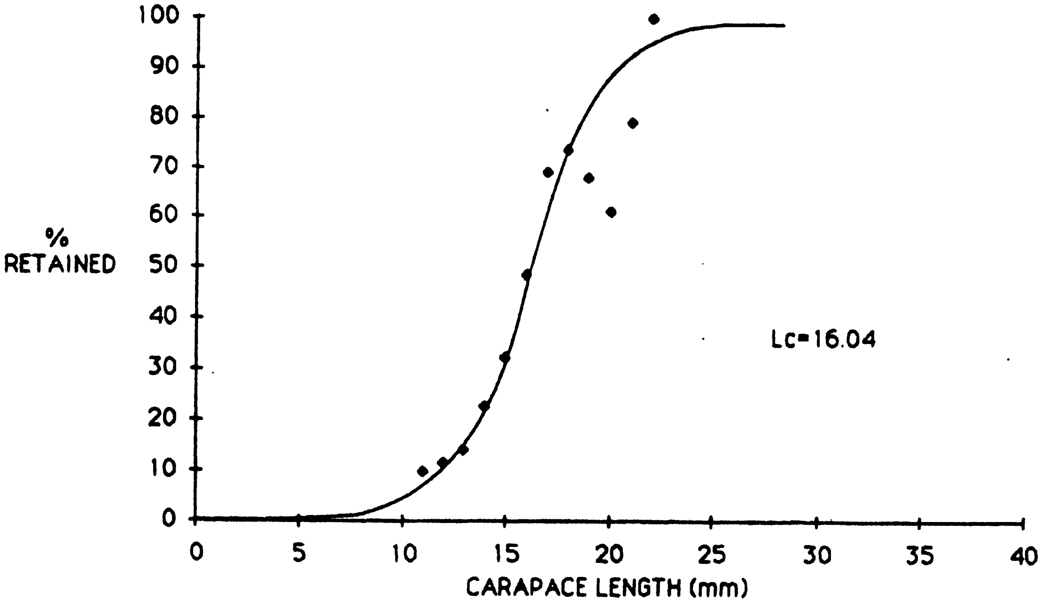


Figure 6: Mesh selectivity curve for *Heterocarpus sibogae* caught in 18mm chicken-wire traps. Frequencies for each 1mm carapace length size class were smoothed by applying a moving average with n=3 (size classes with less than 50 individuals excluded). The fifty percent selection point is at approximately 16mm carapace length.

3. BAIT

Obtaining efficient and relatively inexpensible bait is often a serious constraint in the development of trap fisheries. In many crab and lobster trapping fisheries, considerable effort has been expended in an attempt to develop inexpensive artificial bait. Traditionally, "trash fish" (fish undesirable for human consumption) have been used to bait traps to catch crustaceans.

In Pacific Island countries, however there are very few fish caught which are considered unfit to eat. In addition, there are usually no trawl fisheries to provide "trash fish" to use as bait. In these countries there may be difficulties in obtaining sufficient quantities of bait to sustain a commercial trap fishery.

Several different baits have been tested in Fijian waters (King, 1983). Baits from oily fish such as whole Indian mackerel (Rastralliger kanagurta) and the heads of skipjacks tuna (Katsuwonis pelamis) were the most efficient of those tested. Baits of non-oily fish (mainly Mugilids and Leiognathids) resulted in catches of about 75 percent of those from oily fish baits. As many species of caridean shrimp are cannibalistic, a mixture of shrimp "heads" (cephalothorax) and flour as a "binder" was tested; efficiency was approximately the same as for non-oily fish. In a commercial-size operation in Fiji, chicken offal from a local poultry packing plant was used as bait, but no statistical comparisons were made between the efficiency of this and other baits.

Subject to availability, oily fish (Scombrids and Clupeoids) appear to be he preferred baits. Tuna heads, mackerel and sardines have been successfully used as bait for deep-water shrimp in several Pacific Islands. Tuna heads, for example, have been obtained from local markets and used as bait in shrimp trapping in Western Samoa (King, 1980). Sardines (Sardinella spp) are caught by cast nets in many Pacific Islands, and these have been used in a deep-water shrimp survey in Vanuatu (King, 1981). Both jack mackerel and Pacific mackerel have been used as bait in the Hawaiian Islands (Gooding, 1984). Anchovies, sardines and mackerel are used to bait traps in Japan (N. Iwasaki, pers. comm. 1986).

Where whole fish or fish heads are used as bait these may be hung in the centre of the traps by means of a wire passed through the eyes of the fish and twisted through the covering on the top of the trap. Baits of smaller fish such as sardines, or chopped fish, may be placed in a bait container which is hung from the top of the trap. Bait containers are usually made from the same material as that used to cover the traps (often chicken-wire mesh). Alternatively, screw-top plastic containers drilled with holes can be used; the top of the plastic container can be left permanently hung in the trap and a new container with fresh bait put in place when traps are reset. The use of bait containers may reduce the rapide consumption of bait by shrimps as well as other crustaceans such as isopods and amphipods.

4. FISHING METHODS

Vessels used in trapping surveys and commercial trapping operations in the Pacific Ocean have ranged in length from about 7.5 m to 39 m. (see Section 9). Whatever the size of vessel used, an echo-sounder (capable of detecting depths of up to 1000 m) and a mechanical or hydraulic trap-hauling winch are necessary equipment.

Small volume traps are set in strings, and a typical fishing rig is shown in Figure 7. The fishing rig consists of two parts, a drop-line connected to one or more buoys, and a bottom-line along which the traps are attached with patent spring clips. One of the buoys is attached to a wood or bamboo marker pole with a brightly-coloured flag and a counter weight. In areas of strong surface currents extra float buoys must be used to prevent the marker buoy being pulled beneath the sea surface. Marine authorities in some areas may require a radar reflector or even a flashing light to be attached to the top of the marker pole. A weight of approximately 10 kg or a simple anchor made from 50 mm angle iron and steel rod (Figure.7) is attached from a short length of chain at the joint between the drop-line and the bottom-line. In a commercial fishing operation up to about 100 small traps may be set on a single bottom-line with a drop-line and buoys at each end. Alternatively, particularly on areas of rocky sea-floor, large volume traps may be set individually from a single drop-line.

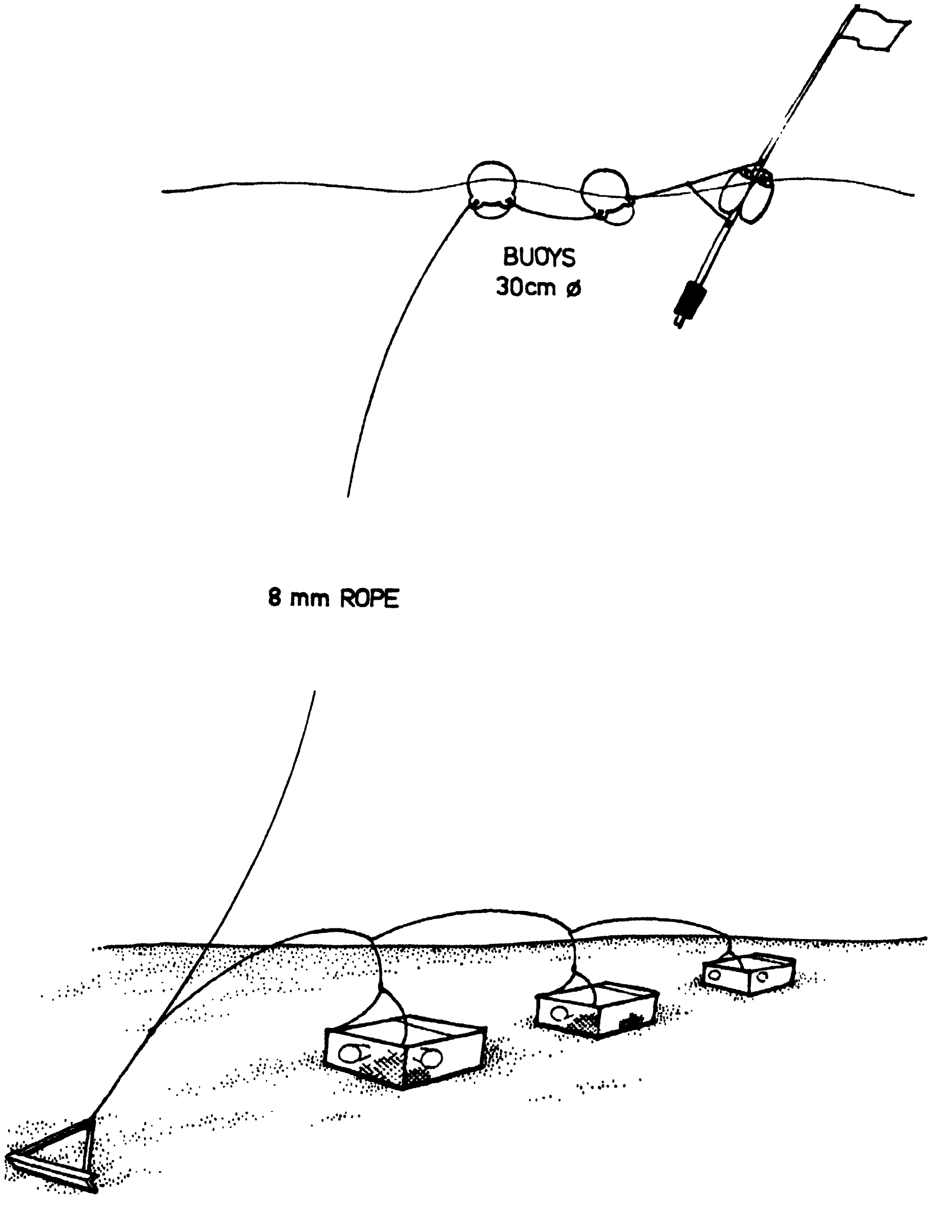


Figure 7: The general arrangement of a trap fishing rig. The length of drop-line used (i.e. between the buoys and the anchor) is equivalent to the depth of water plus an excess of 25 percent. In a commercial operation a single large trap or up to 100 small traps may be set in a similar manner (see text).

The echo-sounder is use to locate suitable fishing depths (see Section 6) and areas where the sea-floor slope is not too steep. Traps set on slopes steeper than about 250 m per km may slide into deeper water (King, 1984); such steep outer-reef slopes as well as rocky sea-floors possibly account for the greatest number of trap losses.

At the selected fishing location, the first trap is connected to the end of the drop-line and lowered over the windward side of the vessel. As the drop-line is fed into the sea, traps are connected at intervals of up to about 30 m; this spacing is to avoid competitive effects between traps. With the engine stopped, the boat drifts off to leeward with the traps acting as a sea anchor during the drop. In this manner, pressure is kept on the drop-line to keep the traps in a straight line and avoid tangling. A drop-line length equal to the depth of water plus about 25 percent is released before connecting the float buoys and marker pole and casting off.

Traps are usually left overnight when catch rates are the highest (see Section 6) and recovered the following day. If traps are left in the sea for longer than the usual 12-18 hour period, cannibalism may reduce catches. The type of winch which is most convenient to use is a "self-tailing" one in which the drop-line is firmly gripped by a pulley and stripped off by a metal peeler. Rope hauled in may be flaked down in bins or directly on the deck of the vessel.

5. SPECIES FOUND

Penaeid and caridean shrimps represent the two large divisions of the nantantian decapod crustaceans. Besides being different biologically (see Section 7) these two divisions can be separated on the basis of the morphological features given in the key below and illustrated in Figure 8.

Division PENAEIDEA

- Third pair of pereiopods chelate (with pincers)
- Pleuron (covering shell) of second abdominal segment not overlapping pleuron of second abdominal segment.

Division CARIDEA

- Third pair of pereiopods non-chelate
- Pleuron of second abdominal segment overlapping pleuron of second abdominal segment.

Several deep-water penaeid shrimp, including Penaeopsis eduardoi, Aristeus virilis and Parapenaeus fissurus, have been caught in small numbers by traps (King, 1984). P. marginatus has been trawled with limited success in Hawaiian waters (Struhsaker and Yoshida 1975). Species of penaeid shrimps also occur in shallow-water habitats such as river mouths and lagoons in some tropical Pacific Islands. However, in deeper waters, beyond the depths of coral formation, caridean shrimps are more common than penaeids and at least sixteen species have been found during trapping surveys in Pacific Islands.

A list of all species of caridean shrimps found in surveys in Fiji, Vanuatu, Western Samoa, Tonga, the Marianas and Hawaii is given in Table 1. In reference to this table it should be noted that the surveys in Vanuatu, Western Samoa and Tonga were of a preliminary nature. A key to the species found in southwestern Pacific Islands is given in Figure 9.

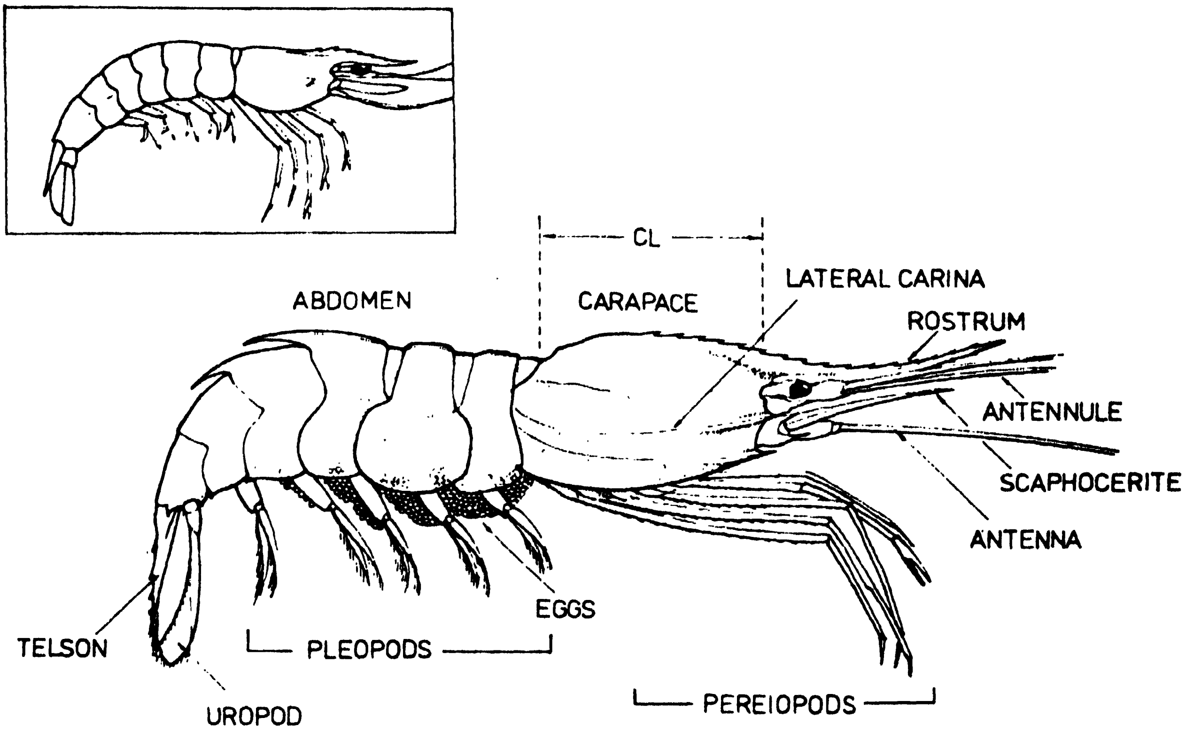


Figure 8: A caridean shrimp showing the external features referred to in the text; a penaeid shrimp is shown in the inset for comparison. In carideans, the pleuron (covering shell) of the second abdominal or "tail" segment overlaps the pleura of both the first and the third segments, the third pair of walking legs does not have pincers, and the dorsal side of the abdomen often has a characteristic hump. The abdomen is often proportionally smaller than that of penaeids. Unlike penaeids, carideans carry their eggs externally beneath the abdomen in the same way as crabs and lobsters. The standard method of measurement (carapace length) of shrimps is shown as CL.

DIVISION CARIDEA

1) Carapace with strong lateral carinae 2
   Carapace without strong lateral carinae 3

2) Prominent hooked dorsal ridge on abdominal somite 3 .... *Eugonatonotus crassus* Ec
   Low ridge or sharp spines on dorsal edge of abdominal somites.. *Heterocarpus*

3) Rostrum long with more than 50 dorsal teeth .... *Parapandalus serratifrons* Ps
   Rostrum with less than 50 dorsal teeth 4

4) First pair of pereiopods without chelae .... *Plesionika*
   First pair of pereiopods with chelae 5

5) Rostrum long with more than 20 dorsal teeth .... *Stylodactylus stebbingi* Ss
   Rostrum short with less than 10 dorsal teeth 6

6) Rostrum broad; pereiopods without exopods .... *Periclimenes* sp. P
   Rostrum narrow; pereiopods with exopods .... *Acanthephyra armata* Aa

GENUS *Heterocarpus*

1) Abdominal somites with median dorsal spines and posterodorsal teeth 2
   Abdominal somites without median dorsal spines and posterodorsal teeth 4

2) Dorsal spines on somites 3 and 4 3
   Dorsal spines on somites 3, 4 and 5 .... *dorsalis* Hd

3) Dorsal spines of equal length; dorsal carinae on somites 1 & 2. *sibogae* Hs
   Dorsal spines on somite 4 smaller than 3; no dorsal carinae on somites 1 and 2 .... *ensifer* He

4) Post rostral teeth on high dorsal ridge; more than 2 teeth anterior to orbit .... *gibbosus* Hg
   No high dorsal ridge on carapace; less than 2 teeth anterior to orbit .... *laevigatus* Hl

GENUS *Plesionika*

1) Rostrum length less than carapace length .... *rostricrescentis* Pr
   Rostrum length more than carapace length 2

2) Dorsal rostral teeth along length of rostrum; red stripes on abdomen .... *longirostris* Pl
   Dorsal rostral teeth only at base of rostrum; pink colour 3

3) Posterior margin of abdominal somite 3 with sharp dorsal tooth. *ensis* Pe
   Posterior margin of abdominal somite 3 without tooth .... *martia* Pm

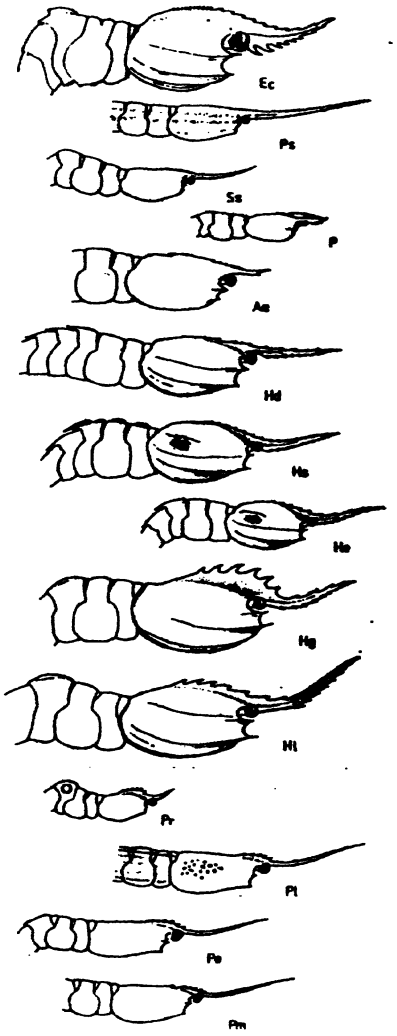


Figure 9: A key to caridean shrimps found in trapping surveys in Southwestern Pacific Islands.

TABLE 1

Caridean shrimps (family *Pandalidae*) found in deepwater trapping surveys in Fiji (Fij.) Vanuatu (Van.), Western Samoa (Sam.), Tonga (Ton.), Marianas (Mar.) and Hawaii (Haw.). The trap abundance of each species is indicated as C (common), O (occasional), R (rare) or no latter (not recorded). From King (1984) and Anon. (1984), and R. Moffit (pers. comm. 1986).

SPECIES	FIJ	VAN	SAM	TON	MAR	HAW
*Parapandalus (=Plesionika**) serratifrons* (pyjama shrimp)	C	C		C		C
*Plesionika longirostris (=edwardsii**)* (starts & stripes shrimp)	C	C	C	C	C	O
Plesionika rostricrescentis	R			R		
Plesionika ensis (striped gladiator shrimp*)	O	O	O	O	R	R
Plesionika ocellus						R
*Plesionika sindoi (=P. ocellus**)*					R	
Plesionika martia (golden shrimp*)	O				R	O
Periclimenes sp.				R		
Eugonatus crassus				R		
Heterocarpus ensifer (armed nylon shrimp*)	O	O		O	C	C
Heterocarpus sibogae (mino nylon shrimp*)	C	C	C	C	R	
Heterocarpus gibbosus (humpback nylon shrimp*)	C	O		R	R	
Heterocarpus laevigatus (smooth nylon shrimp*)	C	C	C	C	C	C
Heterocarpus dorsalis (Madagascar nylon shrimp*)			O		C	
Heterocarpus lepidus					O	
Heterocarpus longirostris					C	
Heterocarpus tricarinatus					R	

* Standard FAO name (Holthuis, 1980)

** Revised names (Chace, 1985)

Species belonging to the genus Heterocarpus, because of their size and abundance, are generally regarded as having the best commercial potential. Brief descriptions of these, and the Plesionika species which are believed to have commercial potential in other parts of the world, are given below. Common names are from Holthuis (1980), where available, or from King (1984).

Plesionika longirostris (Borradaile)
Stars and stripes shrimp

Small rostral teeth along dorsal and ventral edges of rostum with four to six larger dorsal teeth above orbit. Rostrum recurved at anterior end; just over twice the length of the carapace (ratio approximately 5:2). Carapace length up to 28 mm (about 165 mm total length).

Colour in life: Abdomen pale pink with six longitudinal red stripes on each side. Carapace red with clusters of white patches. Vertical white band at posterior edge of carapace. Antennules and antennae pink with white extremities. Eggs bright blue.

Reported from Tahiti (anon., 1979), Hawaii (Western Pacific Fishery Management Council, 1984) and common in Fiji, Vanuatu, Western Samoa, Tonga (King, 1984) and the Marianas (Western Pacific Regional Fishery Management Council, 1984a). Found in the gut of deepwater Lutjanidae and caught in deepwater fish traps in Fiji. Although small, the species has sometimes been caught at catch rates of over 0.5 kg per trap in Fiji; the proportion of recoverable tail meat to total weight in Plesionika is higher than in Heterocarpus species.

Plesionika ensis (A. Milne Edwards, 1881)
Striped gladiator shrimp (FAO name)

Rostrum with five to seven dorsal teeth and many fine ventral teeth. Rostrum recurved and about twice the length of the carapace. A sharp tooth in the middle of the posterior margin of the third abdominal somite distinguishes this species from other Plesionika species found. Carapace length up to 21 mm (about 120 mm total length).

Colour in life: light pink. Pacific specimens do no appear to be striped in spite of the FAO common name; eggs pale blue. Specimens were caught in trapping surveys in Fiji, Vanuatu, Western Samoa and Tonga (King, 1984). Small numbers caught in Hawaii (Clarke, 1972) and the Marianas (Anon., 1984). A circumtropic species (Holthuis, 1980) believed to be of commercial value off the west coast of India (Suseelan & Mohamed, 1969; Suseelan, 1976; Kurian & Sebastian, 1976).

Plesionika martia (A. Milne Edwards, 1883)
Golden shrimp (FAO name)

Similar to P. ensis but without a sharp tooth on the third abdominal somite. Carapace length up to 22 mm (about 130 mm total length).

Colour in life: light pink with blue eggs.

Small numbers caught in Fiji and Western Samoa (King, 1984); also reported from Hawaii (Clarke, 1972) and the Marianas (Western Pacific Regional Fishery Management Council, 1984). A circumtropic species (Holthuis, 1980) believed to have commercial potential off West Africa (Crosnier & de Bondy, 1967), Madagascar (Corsnier & Jouannic, 1973), West India (Jones, 1969), Sumatra and N.W. Malaysia (Longhurst, 1970) and New Zealand (New Zealand Marine Department, 1964). Commercially taken in the Inland Sea of Japan (Yasuda, 1957).

Heterocarpus ensifer (A. Milne Edwards, 1881)
Armed nylon shrimp (FAO name)

Rostrum longer than carapace length. Seven to fourteen dorsal and seven to eight ventral teeth. Carapace strongly marked with three lateral carinae, the upper one being short and restricted to the posterior part of the carapace. Two prominent dorsal median spines; the spine on abdominal somite four about half the length of the spine on somite three. All somites terminate in posterodorsal teeth. Carapace length up to 29 mm (about 125 mm total length).

Colour in life: red to deep red; darker in colour than H. sibogae. Eggs blue to dark blue.

Found in Hawaii (Clarke, 1972; Struhsaker & Aasted, 1974), where it is regarded as having commercial importance, as well as in Guam (Wilder, 1977), New Caledonia (Intès, 1978), Tahiti (CNEXO, 1979) and the Marianas (Moffitt, 1983), Trawled on the Pacific coast of Japan (N. Iwasaki, pers. comm. 1986), Reported to be of commercial potential in Madagascar and Reunion (Crosnier & Jouannic, 1973). Found in surveys in Fiji, Tonga and Vanuatu (King, 1984).

Heterocarpus sibogae (de Man, 1917)
Mino nylon shrimp (FAO name)

Rostrum only slightly longer than carapace length; fourteen to seventeen dorsal teeth and eight to twelve ventral teeth. Carapace strongly marked with three lateral carinae as in H. ensifer. Antennae longer than total body length. Two prominent dorsal median spines of equal length, one on each of abdominal somites three and four, all somites end in posterodorsal teeth. A median longitudinal carina on the first and second abdominal segment separates this species from H. ensifer. Up to 7% of some samples of this species were parasitized by the branchial bopyrid isopod Pseudione magna Shiino. Carapace length up to 41 mm (about 163 mm total length).

Colour in life: pale pink to red (lighter in colour than H. ensifer. Eggs appear to pass through colour changes from bright blue to dark blue/grey with development.

An Indo-West Pacific species (Holthuis, 1980) important in the Inland Sea of Japan fishery (Yasuda, 1957). Also caught in the Marianas and American Samoa (R. Moffitt, pers. comm. 1981). One of the most common species caught in Fiji, Vanuatu, Western Samoa and Tonga (King, 1984).

Heterocarpus gibbosus Bate, 1888
Humpback nylon shrimp (FAO name)

Six to nine post-rostral teeth on a high ridge or crown of variable height. Rostrum with smaller dorsal and ventral teeth. Rostrum length less than the length of the carapace and sharply curved upwards in some specimens. Carapace marked with two lateral carinae. Abdominal somites not adorned with posterodorsal teeth. Antennae very long (over twice total body length). Carapace length up to 42 mm (about 155 mm total length).

Colour in life: pink to red; eggs blue to grey/green.

Obtained in large numbers in Fijian waters but only a few specimens were found in Vanuatu and one individual in Tonga (King, 1984). Found in Papua New Guinea (King, 1982). Believed to have commercial possibilities in southwest India (Jones, 1969; Suseelan, 1976; Kurian & Sebastian, 1976).

Heterocarpus laevigatus, Bate, 1888
Smooth nylon shrimp (FAO name)
Ono shrimp (Hawaiian name)

Rostrum longer than carapace length and slightly recurved; five to six anterior dorsal teeth and five to seven ventral teeth. Carapace marked with two long lateral carinae with a third small carina in a lower posterior position. The third abdominal somite has a raised dorsal ridge but posterodorsal teeth are not present on the somites. Carapace length up to 56 mm (about 217 mm total length).

Colour in life: pink to orange with red vertical stripes on the abdomen at the segment joints. Deep red at the extremities of the uropods, telson and rostrum. Eggs blue to dark blue/grey or brown.

Reported in the Pacific from Hawaii (Clarke, 1972; Struhsaker & Aasted, 1974), Guam (Wilder, 1977), New Caledonia (Intès, 1978), Tahiti (CNEXO, 1979), the Marianas (Moffitt, 1983), Vanuatu, Western Samoa, Fiji, Tonga (King, 1984) and Papua New Guinea (King, 1982). This species is the most promising for commercial trap fisheries in the tropical Pacific. Believed also to have commercial potential in Madagascar (Corsnier & Jouannic, 1973) and Reunion (Gueze, 1976). Commercially fished at present in Hawaii.

Heterocarpus dorsalis Bate, 1888
Madagascar nylon shrimp (FAO name)

Rostrum longer than carapace length with seven to nine dorsal and five to eight ventral teeth. Two prominent and one smaller lateral carinae as in *H. laevigatus*. All abdominal somites ending in posterodorsal teeth with somites three, four and five, each with a prominent dorsal spine. Carapace length up to 39 mm (about 160 mm total length).

Colour in life: pink to white with red vertical stripes on abdomen.

An Indo-West Pacific species (Holthuis, 1980) recorded from southern Africa (Kensley, 1972), Marianas (R. Moffitt, pers. comm. 1981), Western Samoa (King, 1984) and Papua New Guinea (King, 1982). Of possible commercial interest in Madagascar (Crosnier & Jouannic, 1973).

Of the *Heterocarpus* species, *H. ensifer* has been found only in small quantities in Fiji, Vanuatu, Tonga (King, 1984) and New Caledonia (Intès, 1978) but in larger quantities in northern Pacific islands such as Hawaii (Struhsaker & Aasted, 1974), Guam (Wilder, 1977) and the Marianas. Individuals of this species caught in the southern Pacific Ocean appear smaller than those caught in the northern Pacific. *H. sibogae*, on the other hand, is more commonly found in the South Pacific.

H. gibbosus, which forms a large part of the catch in Fiji, has only occasionally been found in other southern Pacific Islands and rarely in the northern Pacific. *H. laevigatus* is widely distributed in Pacific Islands, and because of its large size and abundance is of greatest commercial interest.

Several other organisms have been commonly caught in traps set for deep-water shrimps (Figure 10). The more notable of these include snapper (Lutjanidae), particularly *Etelis* and *Pristipomoides* species, in depths less than 300 m, and several species of eels at all depths. In Fiji, *Nautilus pompilius* has been taken (up to 12 individuals per trap) in depths of less than 380 m (King, 1984). Another nautilus, *N. macromphalus* which is unique to New Caledonia, has been caught in deep-water traps (Intès, 1978). Nautilus shells may represent a valuable by-catch for the tourist market in

Pacific Islands. The deep-sea red crab, Geryon, a species of which is of commercial interest in the United States of America (Wigley et al., 1985), has also been caught in depths greater than 600 m in both Fiji and New Caledonia. Amphipods and isopods including a giant Bathynomus species sometimes enter traps in large numbers and devour bait which is not protected by a plastic or small mesh container (see Section 3).

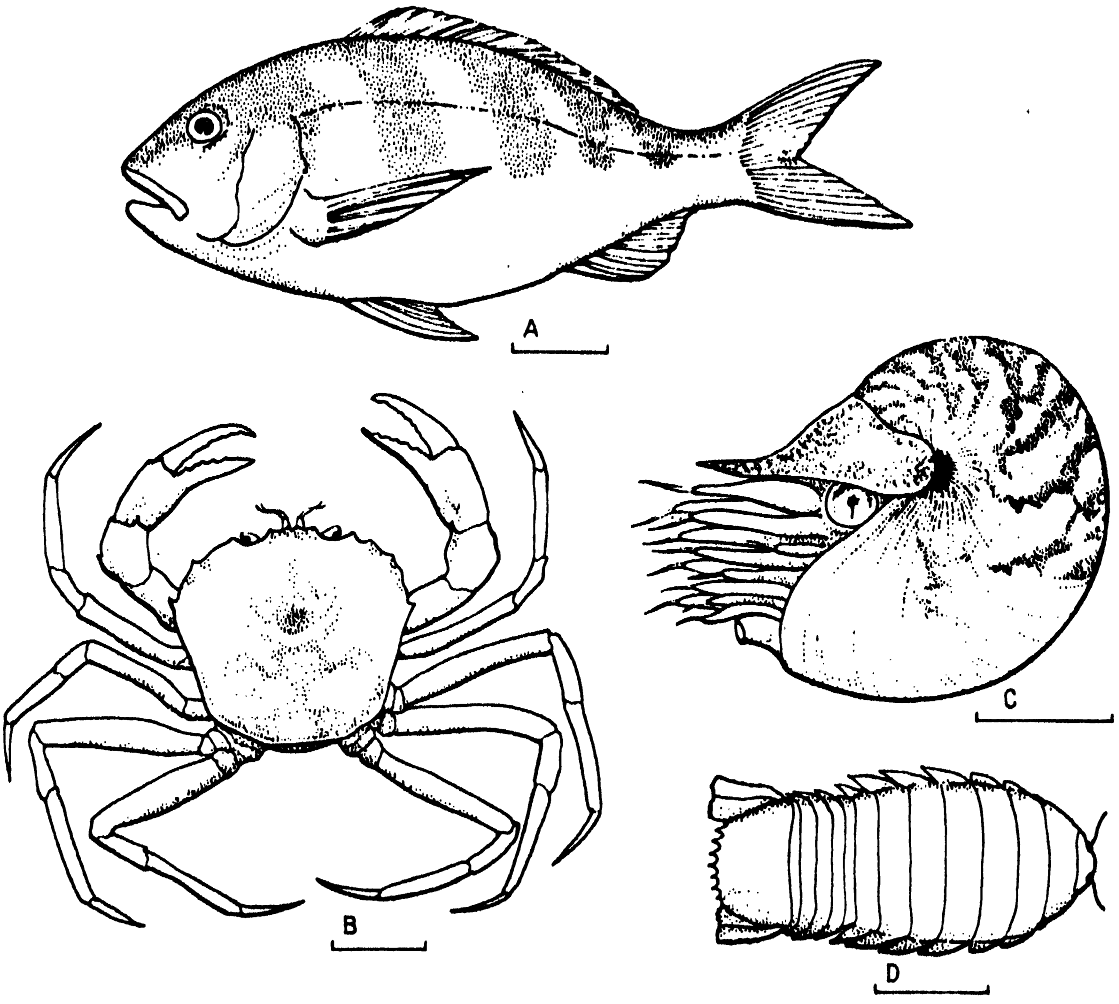


Figure 10: Organismes, other than shrimps commonly caught in deep-water traps set in Pacific Islands: A) snappers such as Pristipomoides species, B) the red crab Geryon, C) Nautilus species and isopods including D) a giant Bathynomus species. Scale lines represent 5cm.

6. DISTRIBUTION BY DEPTH

The distribution of deep-water shrimps is highly related to depth with each species occupying different but overlapping depth ranges. Each particular species of shrimp inhabits a preferred depth range. As traps are set at increasing depths and distances from the shore or reef, catches of each species reach a maximum before decreasing and being replaced by another, and often larger species in deeper water. The mean catch per trap-night at different depths for the main species caught during surveys in Fiji, Vanuatu, Samoa and Tonga (from King, 1984) are shown in Figure 11; catch rates for Fiji are means from surveys conducted over an extended time period.

In general, shallow water catches (from less than 400 m) consist of smaller shrimps such as Parapandalus serratifrons and Plesionika longirostris. Medium-sized Heterocarpus species, predominate in catches over 400 m and one of the largest species found, Heterocarpus laevugatus, is common in depths of more than 500 m. The general depth distribution of the more common species of deep-water shrimps is shown in Figure 12; it should be noted, however that the depth of maximum abundance of each species may vary between island as shown in Figure 11. The differences between the reported depth distributions of one of the most common species, Heterocarpus laevigatus, are compared in Figure 13.

It is difficult to compare the relative catch rates of deep-water shrimps in different islands due to the effects of using different traps, bait and soak times in the various surveys. Table 2 lists the mean catch rates at optimum depth ranges from several areas where surveys have been conducted using small traps (between 0.2 and 0.3 m^3); larger traps, more recently preferred by commercial fishermen in Hawaii, are reported to catch at least five times more shrimps than small traps (Methot, 1984).

It should be noted, when referring to Table 2, that the surveys in Western Samoa, Vanuatu, Tonga and New Caledonia were of a preliminary nature. The most extensive surveys have been carried out in the Hawaiian Islands while the most extended surveys in a given location were conducted near Suva in Fiji.

The Fijian surveys have provided some information on the possible seasonality in catches of deep-water shrimps. Figure 14 shows the mean catch rates of three species. Heterocarpus sibogae, H. gibbosus and H. laevigatus, for each depth during trapping surveys down the outer reef slope near Suva in Fiji (King, 1984). Analyses of variance in these data indicate that mean catch rates, from all depths combined, did not vary significantly between different survey times. This suggests that seasonal effects on any fishery based on these species are not likely to be great. In all species, however, there was significant interaction ($P<0.01$) between the effects of time and depth. This suggests that the depth distributions of these species may change seasonally; in H. gibbosus, at least, the data in Figure 14 may indicate an annual cyclic migration up and down the sea-floor slope.

Heterocarpus leavigatus, in Hawaiian waters appears to migrate from depths of around 550 m to depths of 700 m during the egg-bearing season (Dailey and Ralston, in press).

Other cyclic migrations of shrimps may also affect their catchability. There is some evidence, for example, that Heterocarpus species make vertical migration in the water column. Individuals have been found in the stomach contents of skipjack tuna (katsuwonus pelamis) in Fiji (R. Stone, pers. comm. 1982) and in Hawaii, (R. Spencer, pers. comm. 1982) and several small (<10mm C.L.) specimens of H. ensifer were found in samples caught in midwater trawls towed obliquely from about 1100 m to the surface in areas off Hawaii where the depth was over 2000 m (King, 1984). During 24 hour sampling stations conducted off Suva, *H. sibogae* and *H. gibbosus* were caught in greatly reduced numbers during *the hours* of *surface daylight* (King, 1983); it is not known whether low daytime catch rates are a result of the shrimps burrowing (see Section 7) or moving up into the water column during daylight.

Table 2

Mean catch rates (in kg per trap per night) using *small* traps (volume between 0.2 and 0.3 m^3) in Pacific Islands. Catch *rates* are quoted or inferred from the sources given. Optimum depths generally refer to depths of maximum catch rates of mixed species.

Location	Catch Rate (kg/trap)	Optimum Depth (m)	Comments and Reference
Hawaii Northwestern group	2.9	550-600	Catch of *H. ensifer* and *H. laevigatus* combined (Gooding, 1984)
Guam Western coast	2.1	440-680	Catch of *H. ensifer* and *H. laevigatus* combined (Wilder, 1977)
Western Samoa near Apia	1.4	500-600	Catch of *H. sibogae* and *H. laevigatus* combined (King, 1980, 1984)
Tonga near Nuku'alofa	0.6	600-700	Catch of *H. sibogae* and *H. laevigatus* combined (King, 1981b, 1984)
Fiji Near Suva	1.2	450-650	Catch of *H. sibogae*, *H. gibbosus* and *H. laevigatus* combined (King, 1984)
Vanuatu near Port Vila	2.8	500-600	Catch of *H. sibogae*, and *H. laevigatus* combined. (King, 1981a, 1984)
New Caledonia Loyalty Islands	2.0	800	Catch of *H. laevigatus* (Intès, 1978)

Optimum depth range for *H. laevigatus*

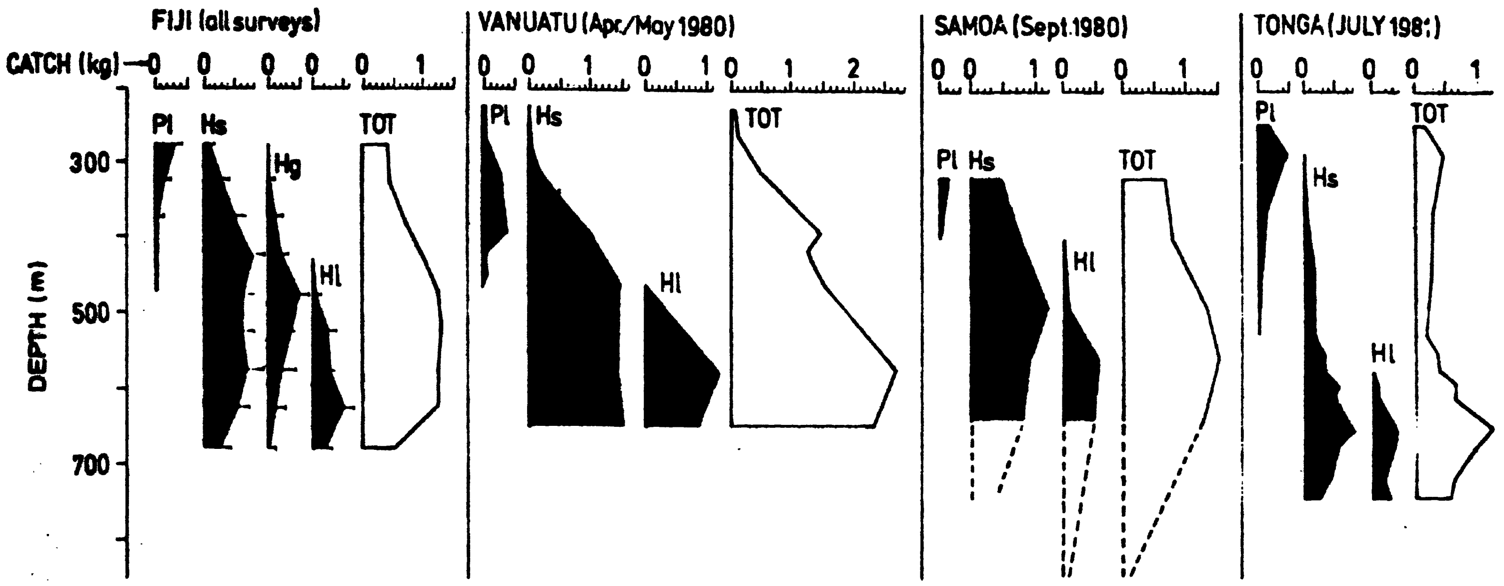


Figure 11: The depth distribution (mean catch in kg per trap) of the most abundant caridean shrimps caught during trapping surveys in (from left) Fiji (all surveys combined), Vanuatu, Western Samoa, and Tonga. Species are (Pl) *Plasionika longirostris*, (Hs) *Heterocarpus sibogae*, (Hg) *H. gibbosus* and (Hl) *H. laevigatus*. Total catch (TOT) is also indicated. Standard deviations for the Fiji data are shown by horizontal bars.

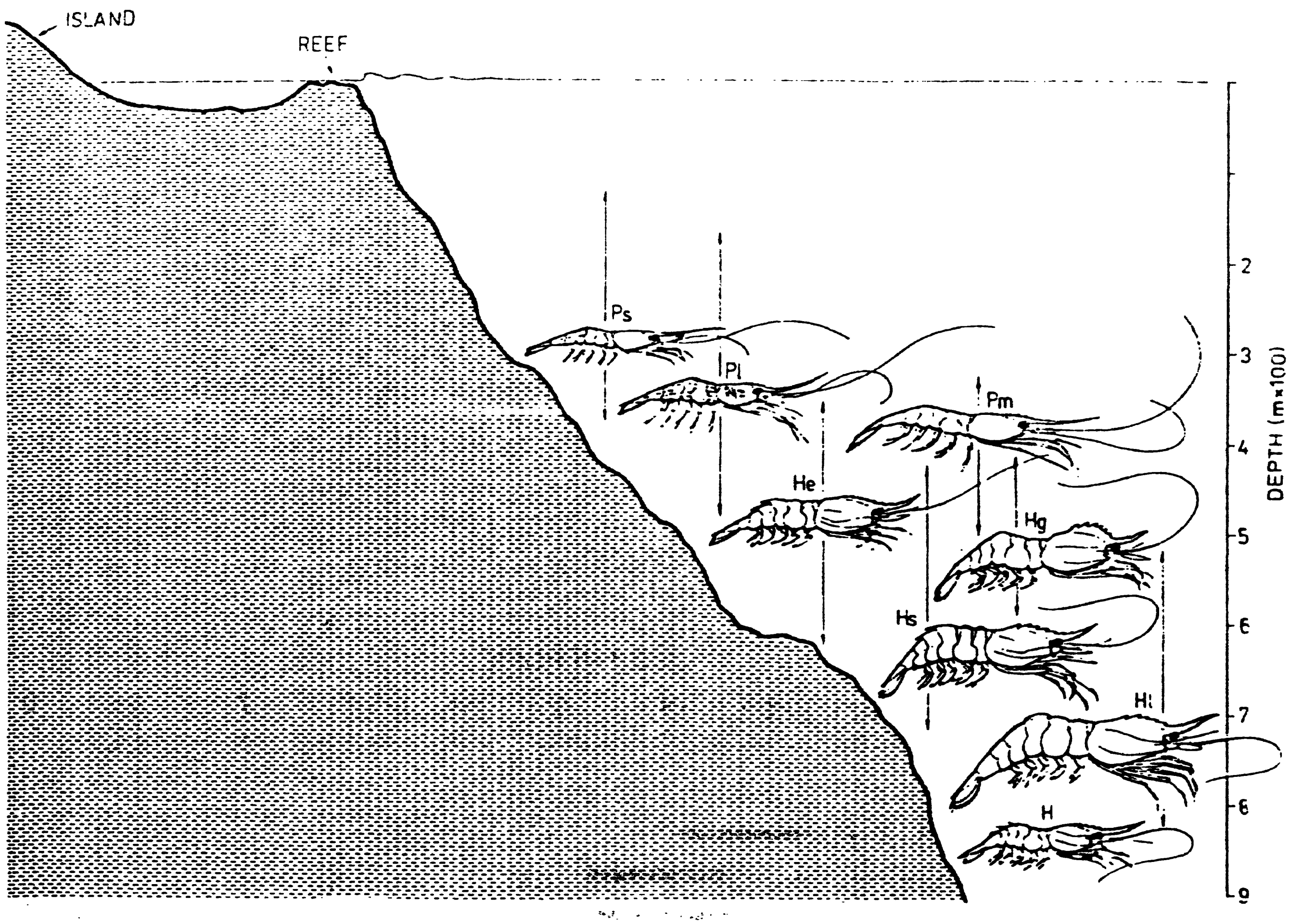


Figure 12: The general distribution of the most commonly found deep-water shrimps at various depths (in meters) near tropical Pacific Islands. The vertical lines represent the approximate depth range of maximum abundance for each species. These depths differ to some degree in different areas and each species is not necessarily found in all of the islands mentioned in the text. Species illustrated, from shallow to deep are: (Ps) *Parapandalus serratifrons* (Pl) *Plesionika longirostris*, (Pm) *Plesionika martia* and *P. enis*, (He) *Heterocarpus ensifer* (Hg) *Heterocarpus gibbosus*, (Hs) *Heterocarpus sibogae*, (HT) *Heterocarpus laevigatus* and (Hd) *Heterocarpus dorsalis*.

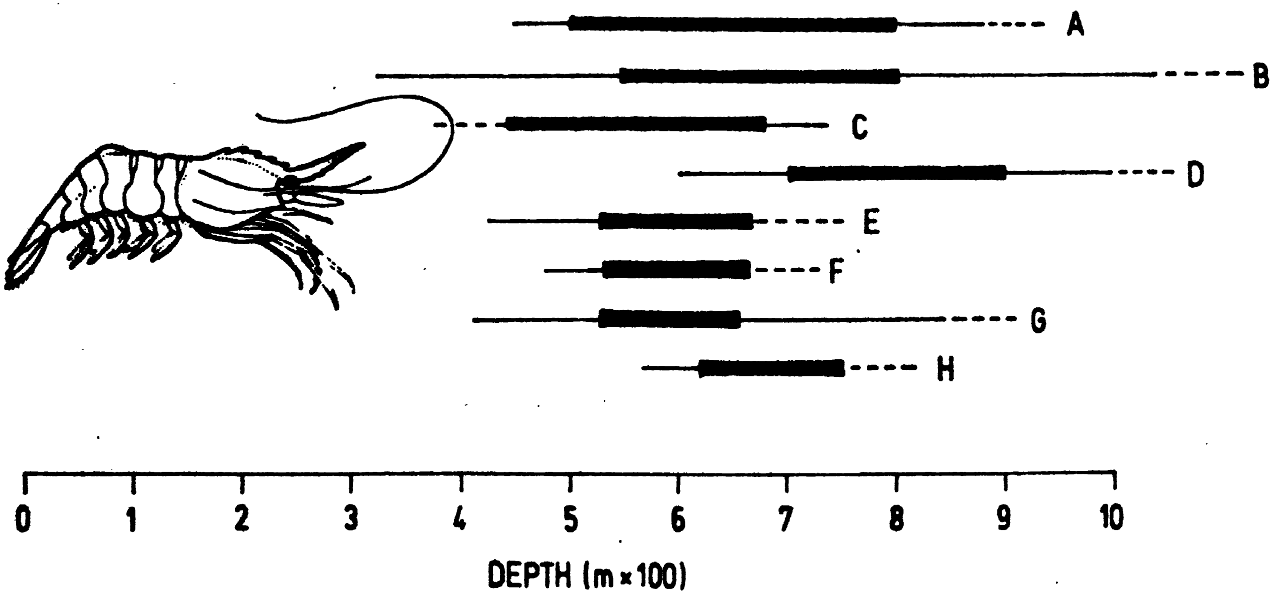


Figure 13: The depth distribution (ligth line) and depth of greater abundance (heavy line) fo *Heterocarpus laevigatus* in A) Hawaii (Gooding, 1984); B) Marianas (Moffit and Polovina, in prep.); C) Guam (Wilder, 1977); D) New Caledonia (Intès, 1978); E) Fiji (King, 1984); F) Vanuatu (King, 1981a); G) Western Samoa (King, 1980) and H) Tonga (King, 1981b). Broken lines indicate the limits of the respective surveys.

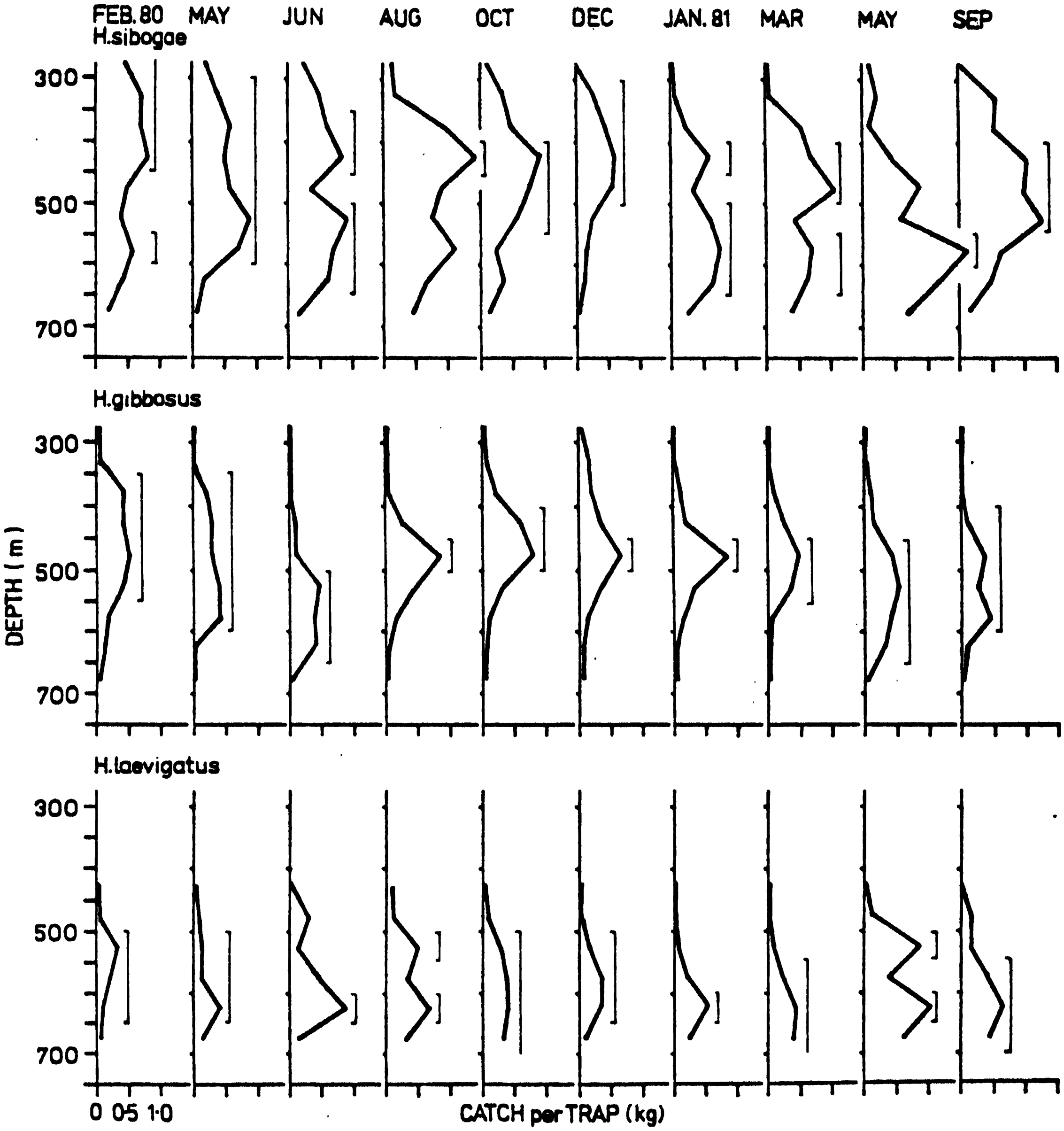


Figure 14: Mean catch rates (kg per trap) by depth of Heterocarpus siboage (top), H. gibbosus (middle) and H. laevigatus (bottom) caught off Laucala Bay, Fiji during surveys from February 1980 to September 1981 (King, 1984), Brackets enclose maximum catch rates which are not significantly different (P>0.05) from adjacent catch rates (Student-Newman-Keuls test).

7. BIOLOGICAL ASPECTS

Although much is known of the biology of penaeid shrimp and cold-water caridean (pandalid) shrimp, very little is known about tropical deep-water carideans. This is because of the difficulty of studying deep-water species and because interest in exploiting tropical caridean shrimps has been comparatively recent. The morphology and biology of caridean shrimps are markedly different from penaeids (Figure 8); unlike penaeids, caridean shrimps carry fertilised eggs attached to their swimming legs or pleopods for extended time periods. Commercial penaeids all have separate sexes whereas many temperate-water pandalid shrimps are protandrous hermaphrodites, i.e. they begin life as males and, later, change sex to become females (Butler, 1964).

Unlike the majority of temperate-water, exploited carideans, and contrary to earlier reports (Clarke, 1972; Wilder, 1977; King, 1981) tropical deep-water shrimps exhibit no sex-reversal (King and Moffit, 1984). In all but the largest size-groups sex ratios are approximately 1:1.

The sex of caridean shrimps can be determined by an examination of the shape of the endopods of the first pleopods (swimming legs); the endopod in males is broader and more leaf-shaped than in females (Figure 15). A mature male also possesses an appendix masculina situated between the appendix interna and the endopod of the second pleopod (Figure 15).

The eggs carried by deep-water pandalids are often brightly coloured, and the intensity of the colour appears to depend on the developmental stage of the eggs. With increasing development, eggs become lighter in colour with development of the transparent blastoderm and larval body. Finally, eggs become darker in colour with the development of larval pigmentation and eye-spots.

The eggs of shallower water species such as *P. serratifrons*, *P. longirostris*, *H. ensifer* and *H. sibogae* progress through shades of blue colour stages with development. The eggs of deeper species such as *H. gibbosus* and *H. laevigatus* vary in colour from olive green to grey/brown. Within species, eggs sizes tend to increase with increasing larval development and, between species, eggs are generally larger in the larger, deeper-water species (Figure 16 and Table 3).

Within species, brood size (the number of eggs carried) appears to be linearly related to female weight (Figure 17). This relationship is likely to be a result of the area available for egg attachment as well as the female's capacity for obtaining, storing and converting resources for egg production (King and Butler, 1985). Mean brood sizes for several species caught in Fijian waters are given in Table 3.

The mean size of reaching sexual maturity in females (defined as the size where 50 percent of the female population is ovigerous) is given for several pandalid shrimp in Figure 18. At the time of reaching sexual maturity, females appear to acquire deeper abdominal pleura (covering "plates" on the abdomen), particularly the second pleuron (Figure 19) which may have a function in protecting developing eggs carried on the pleopods.

The incidence of ovigerous females appears to vary with time of the year. In Fiji, over 50 percent of female *Heterocarpus laevigatus* were carrying eggs in April 1979, June and July 1980 and May 1981 (King, 1983). In Hawaii, the corresponding time period for the same species was October to January (Dailey and Ralston, in prep.). The spawning season of *H. laevigatus* therefore, appears to be in the winter season of each hemisphere.

TABLE 3: Depths of maximum abundance, mean lengths of well-developed eggs and brood sizes at mean reproductive weight for several species of caridean shrimps. Standard deviations are in parentheses. From King and Butler (1985).

SPECIES	Depth (m)	Egg Length (mm)	Brood size
Parapandalus serratifrons	200	0.62 (0.05)	1 344 (183)
Plesionika longirostris	275	0.70 (0.04)	13 721 (847)
Heterocarpus ensifer	425	0.69 (0.04)	2 864 (145)
Heterocarpus gibbosus	475	0.78 (0.06)	28 312 (1 195)
Heterocarpus sibogae	500	0.68 (0.04)	23 292 (2 266)
Heterocarpus laevigatus	625	0.87 (0.09)	34 461 (1 352)

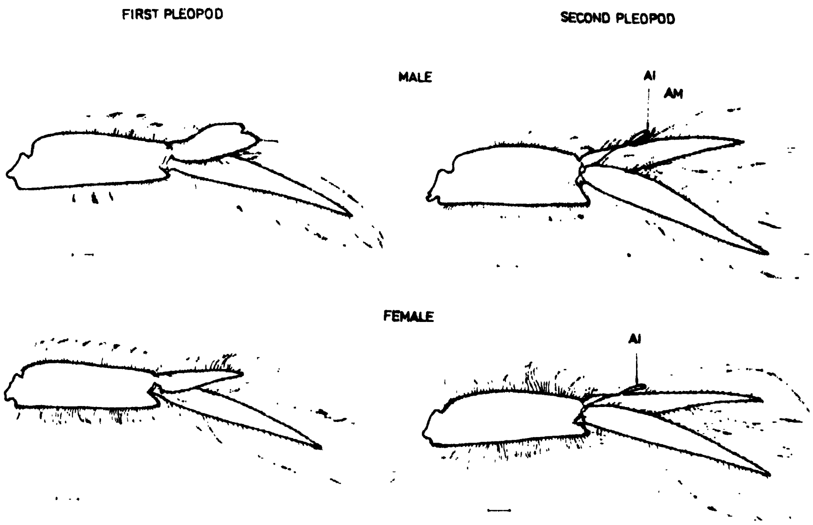


Figure 15: The first and second pleopods (swimming legs) of *Heterocarpus sibogae*. Left: the first pleopod showing the male (top) and female (bottom) endopod. Right: the second pleopod with the appendix masculine (AM) and appendix interna (AI) of the male (top) and the latter organ only in the female Bottom). Pleopods illustrated are from a 26.0 mm carapace length male and a 26.3 mm female. Horizontal scales indicate 1 mm. From King and Moffitt (1984).

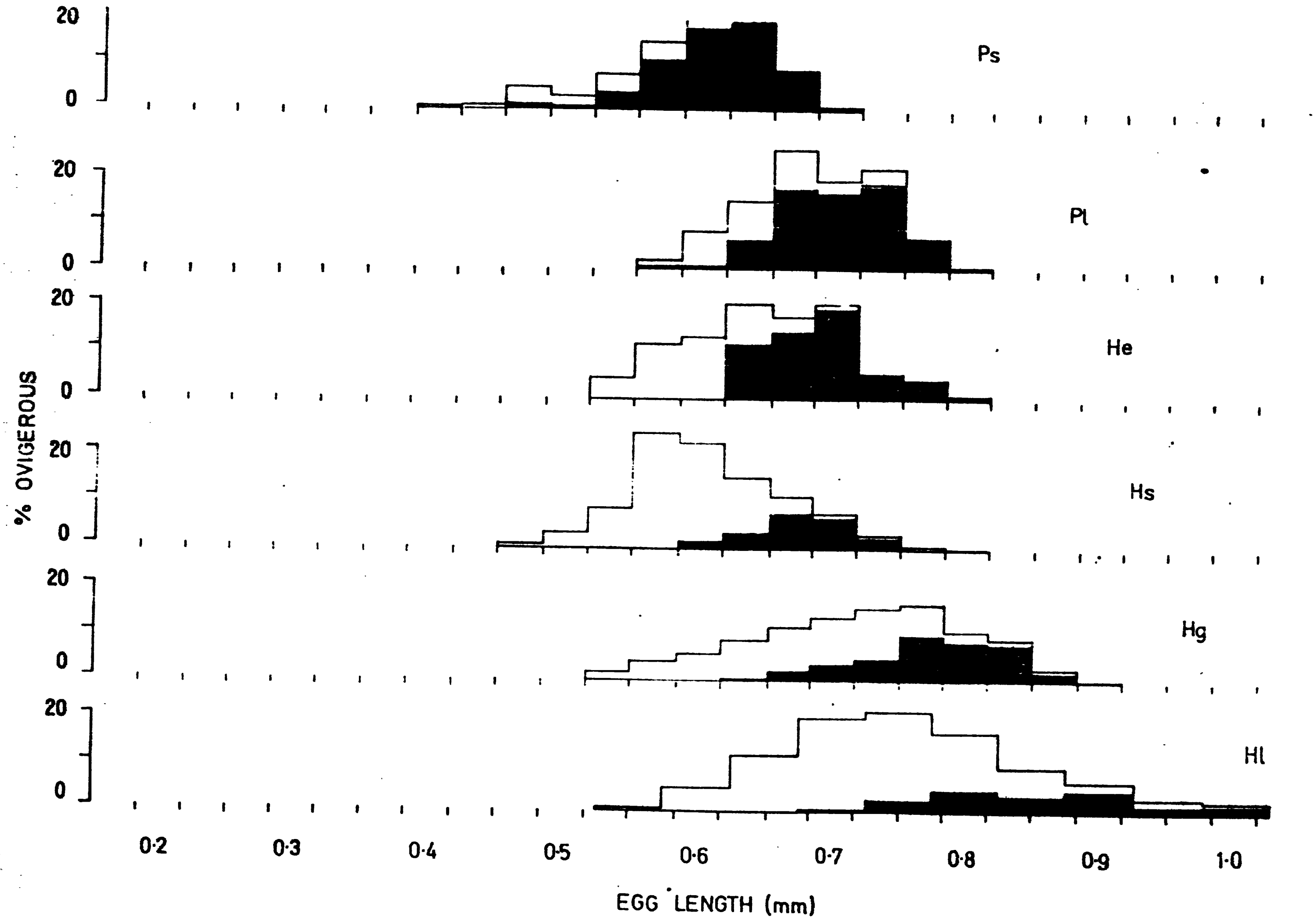


Figure 16: Egg length-frequency distributions for several species of caridean shrimps; species are indicated as in Figure 12. The solid black area of each distribution represents eggs as the most developed stage (from King & Butler, 1985).

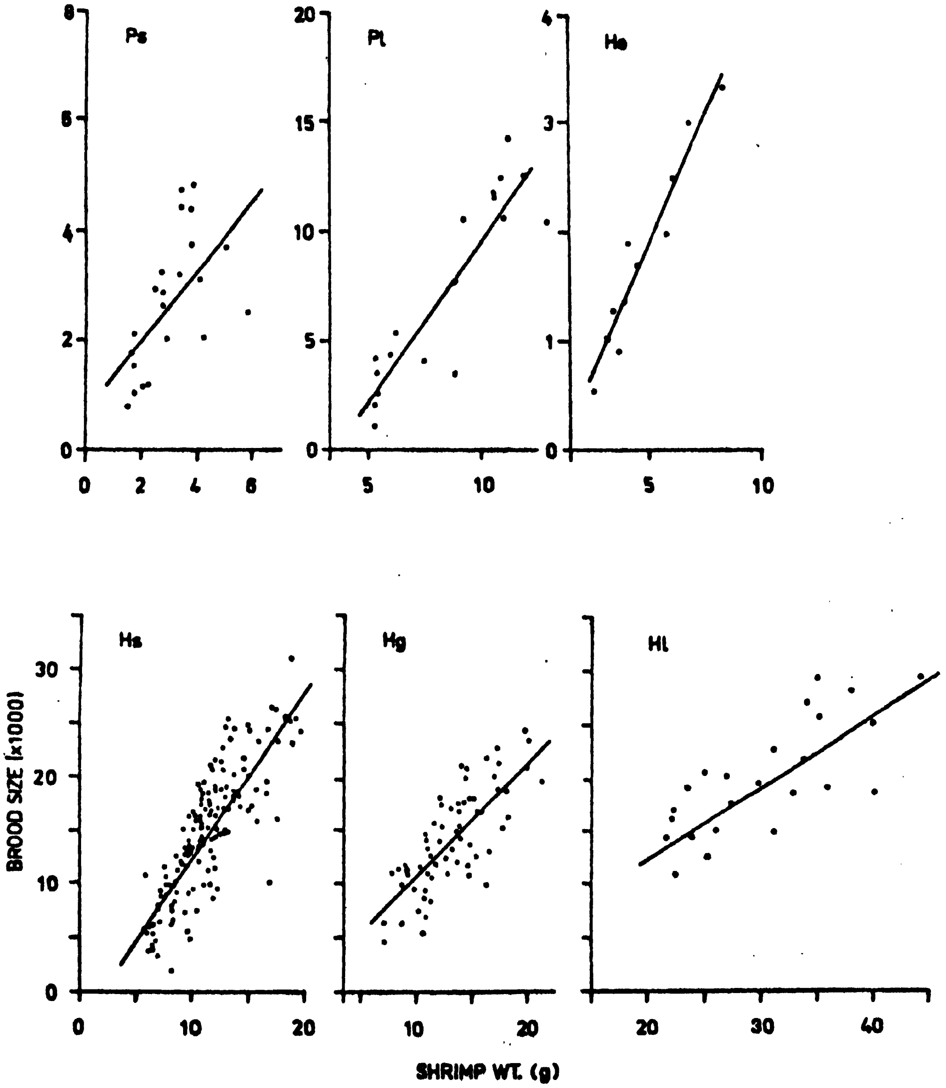
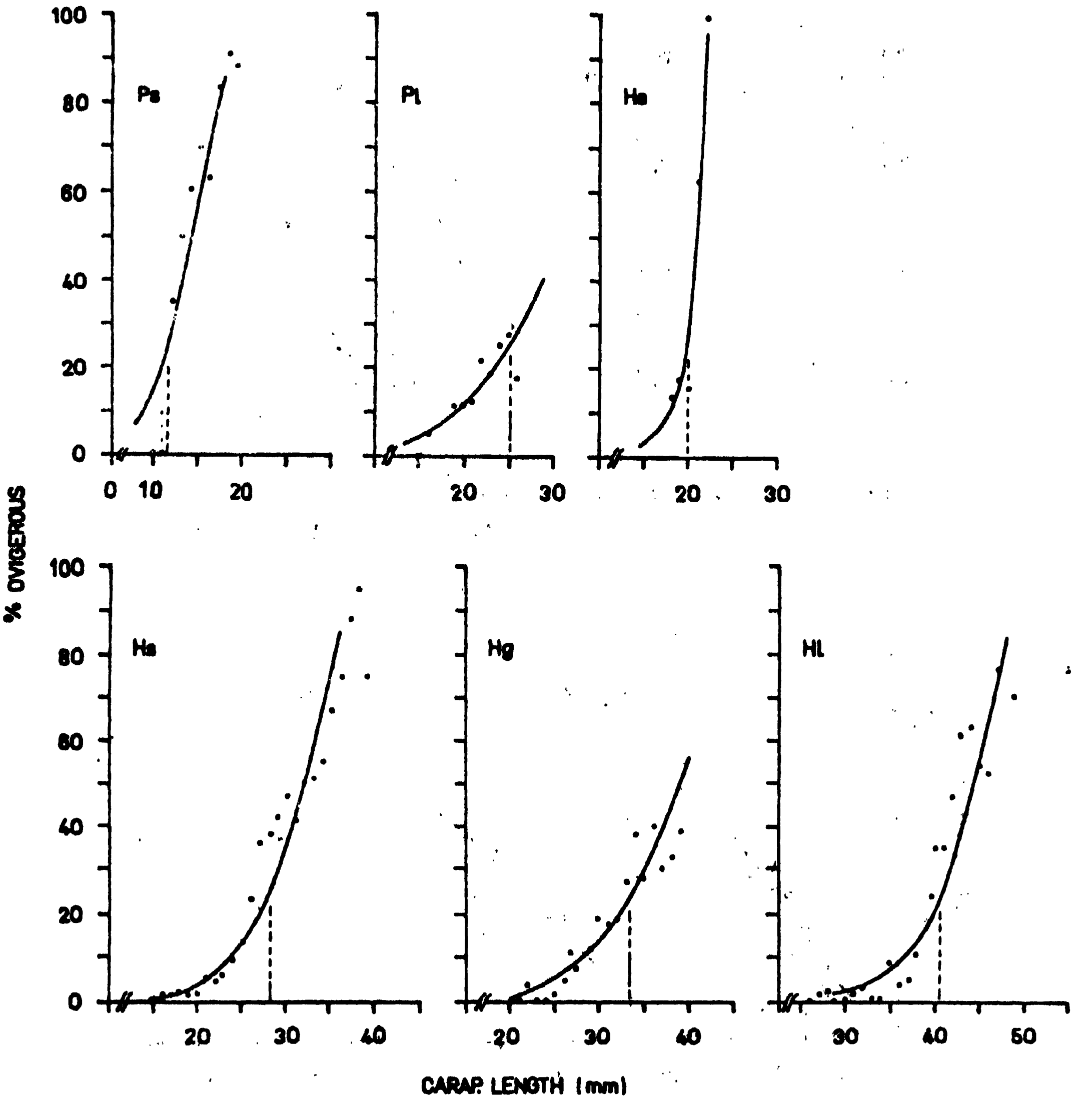


Figure 17: Relationships of broad size to shrimp wet weight with eggs removed. Regression-line statistics and coefficients of determination are, (Ps) Y= 628X-735, r^2 = 0.31; (Pl) Y= 1 447X - 4 830, r^2 = 0.81; (He): Y= 462X - 421, r^2 = 0.92; (Hs): Y= 1 1 530X - 2 7840, r^2 = 0.67; (Hg) Y = 1 100X - 222, r^2 = 0.58; (Hl): Y = 680X - 1 300, r^2 = 0.47. Species labelled as in figure 12.



igure 18: Relationship between carapace length and percentage of whole sample (including males) which comprised ovigerous females in each 1 mm size class. Estimated size at female sexual maturity is indicated by vertical dashed lines. Samples sizes range from 67 in He to 11 654 in Hs. Species are indicated by letters as in Figure 12.

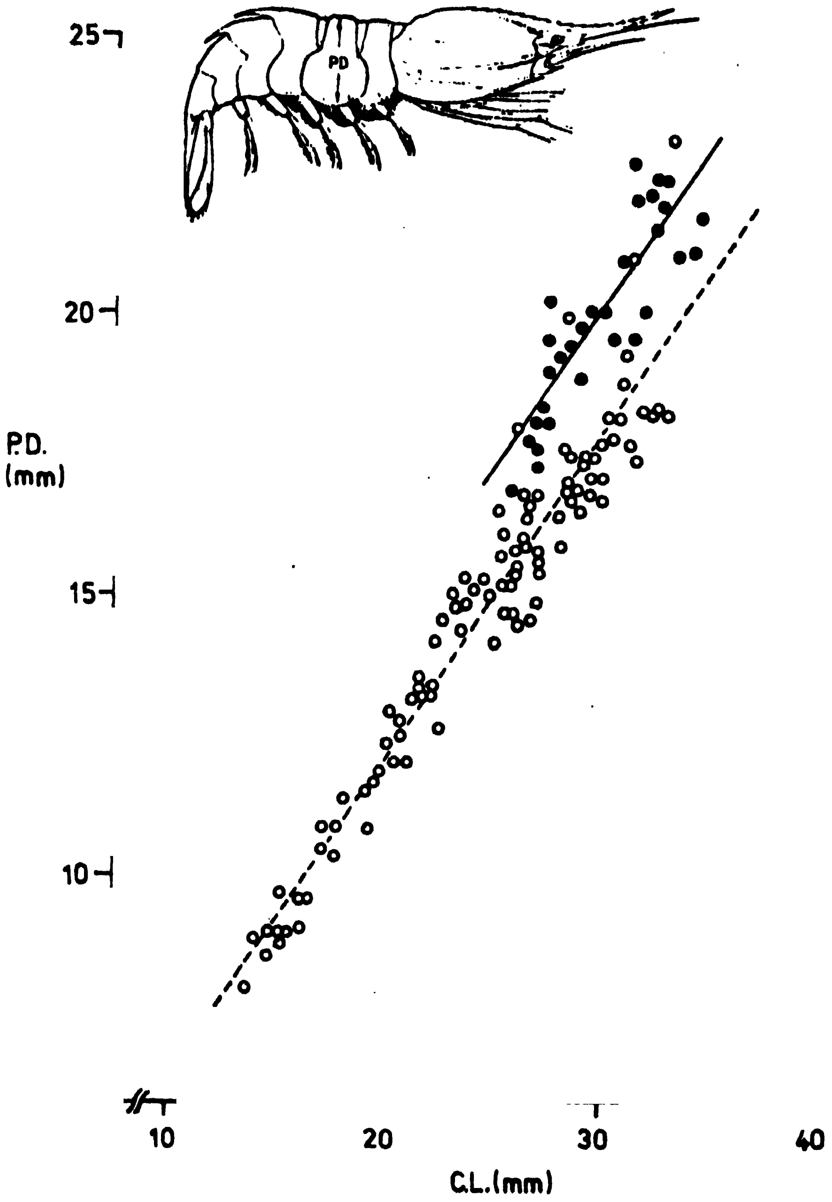


Figure 19: The relationship of the depth of the second abdominal pleuron (PO) to shrimp carapace length (CL) for ovigerous (solid circles) and non ovigerous (open circles) *Heterocarpus sibogae.* The pleudon dimension used is shown above. Regression lines are Y = 3.1 + 0.56 (ovigerous) and Y = 0.67 + 0.57 X (non-ovigerous). Coefficients of determination are 0.74 and 0.93 respectively.

The analysis of length-frequency data is the only method available for estimating growth in deep-water shrimps. Crustaceans have no persistent hard parts to allow the analysis of growth rings (the exoskeleton is lost during moulting) and tagging experiments are not practicable on deep-water species. Length-frequency distributions, on the other hand, are often multi-modal for deep-water shrimps (Figure 20); arranging these distributions sequentially over an extended time period allows the progression of peaks or modes to be used to estimate growth. This method has been used to estimate the growth of several species in Fiji (King. 1983; King and Butler, 1985) and of *Heterocarpus laevigatus* in Hawaii (Dailey and Ralston, in prep.) and the Marianas (Moffitt and Polovina, in prep.) Growth curves, for both sexes combined, are shown in Figure 21 and the von Bertalanffy growth parameters are summarised in Table 4. Data from the Marianas indicate that male *H. laevigatus* grow more quickly than females but reach a smaller ultimate size.

TABLE 4: Von Bertalanffy growth parameters sexual maturity and life span data for tropical deep-water shrimps.

STUDY AREA (Reference) & SPECIES	K (yr^{-1})	L∞ (mm)	Sexual maturity		Lifespan (yr)
			CL (mm)	age (yr)	
FIJI (King 1983)					
Plesionika longirostris	0.66	29.5	25.0	2.0	3.5
Heterocarpus gibbosus	0.44	45.0	28.5	3.1	5.2
Heterocarpus sibogae	0.38	41.0	33.5	3.1	6.1
Heterocarpus laevigatus	0.27	57.0	40.5	4.6	8.5
HAWAII (Dailey and Ralston, in prep.)					
H. laevigatus (males)	0.35	57.9			
(females)	0.25	62.5	40	4	
MARIANAS (Moffit and Polovina, in prep.)					
H. laevigatus (males)		51.3	36	3.5	
(females)		55.4	43	4.5	
(combined)	0.30	55.2			

Growth data for *Heterocarpus laevigatus* (sexes combined) suggest that individuals have a mean age of first capture of about 1.2 years (16 mm carapace length - see Section 2) and females become sexually mature at approximately 4 to 5 years (40.5 mm carapace length from Figure 18). The age of the largest-size groups in samples is over 8 years. Note that it is not possible to age deep-water shrimp precisely and the estimated ages given above assume that growth throughout life follows the von Bertalanffy curves shown in Figure 21; this may not be so, particularly if larval growth differs markedly from that of adults.

Length-frequency data may also be used to estimate mortality rates. Figure 22 shows the mean abundance of *Heterocarpus laevigatus* over age from data collected in Fiji. Individuals younger than age 4 years were believed to have been incompletely sampled by the traps due to mesh selectivity (see Section 2). A regression line fitted to the descending part of the graph provides an estimate of total mortality, Z, equal to 0.66 (about 48 percent per year). As this population was unexploited, except for the surveys at one or two month intervals, the value for natural mortality rate is likely to be similar. In the Marianas natural mortality was estimated to be 0.75 per year (Moffitt and Polovina, in prep.).

Preliminary estimates of total mortality rates for exploited populations of *Heterocarpus laevigatus* in Hawaii were $Z = 1.51$ yr^{-1} (about 78 percent) for males and $Z = 0.75$ yr^{-1} (about 53 percent) for females (Dailey and Ralston, in press).

There are very few details on behavioural aspects of deep-water shrimps other than the migrational behaviour referred to in Section 6. Some information is available from observation in refrigerated aquaria (King, 1983) *Heterocarpus* species appear to feed by probing the substrate with their maxillipeds and pereiopods and passing small food particles to the mouth parts. The ability rapidly to detect large pieces of food placed in the aquarium suggests that chemosensory mechanisms are involved in food location. When disturbed in the aquaria, several *Heterocarpus* species were observed to discharge luminous blue clouds of material from an area near the mouth parts. The discharge was usually accompanied by a violet reflex of the abdomen and rapid backward movement by the individual.

From aquaria observations it appears that *Heterocarpus* species do not burrow in the substrate, as penaeids do, but may form depressions in the seafloor through the action of the pereiopods. This is also supported by observations of deepwater shrimps on video film taken from the miniature submarine "Makali'i" and seen by the author in Hawaii. Video films taken at a dredge dumping site in 360 m off Oahu (D. Chave unpublished data, 1982) showed specimens of both *H. ensifer* and *Plesionika* species on the surface of the substrate.

8. YIELD

The discovery of quantities of deep-water shrimps in Pacific Island countries has resulted in a number of optimistic reports, several by private companies wishing to attract investment, on prospects for an offshore trap fishery. Problems, such as the high cost of fishing in deep water and the practical difficulties of handling and marketing the catch are discussed in following sections of this report. More recent biological information, particularly on the estimated high natural rates of some species, suggests the need for caution in encouraging large-scale exploitation.

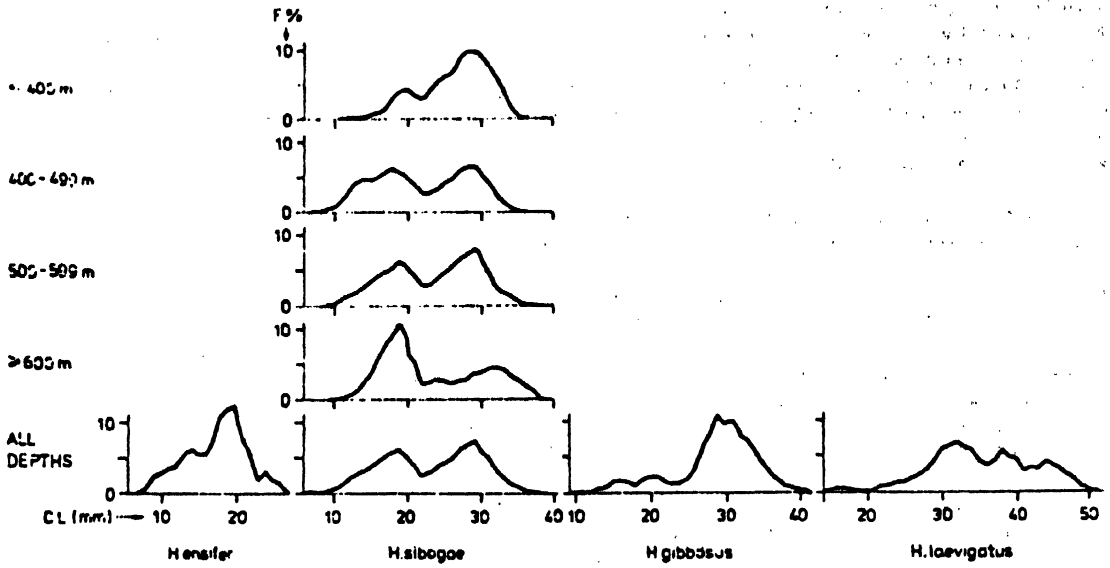


Figure 20: Length-frequency date for Heterocarpus species caught during surveys in Fiji 1981. Data for H. sibogae are presented for four different depth ranges and for all depths combined. Samples sizes range from 242 to 2754.

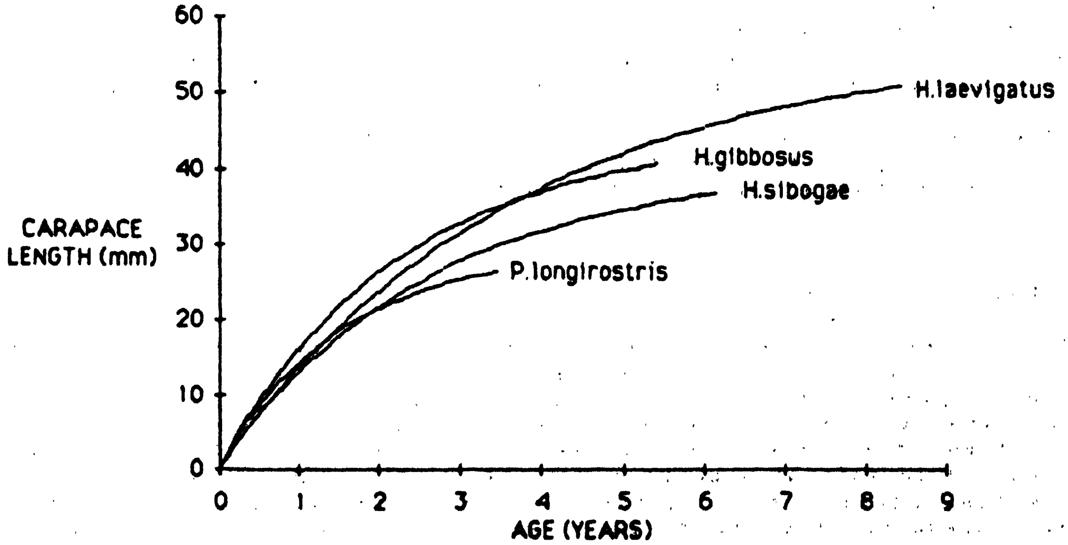


Figure 21: Growth curves from Plesionika longirostris, Heterocarpus sibogae, H. gibbosus and H. laevigatus. The curves have been terminated at 90 percent of the theoretical maximum length.

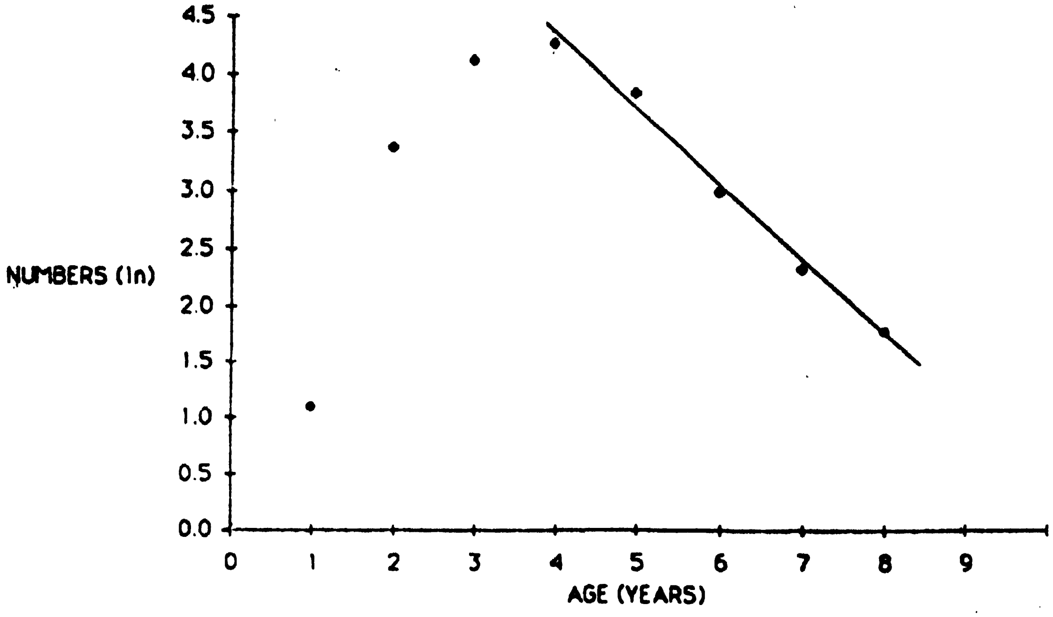


Figure 22: Mean abundance of Heterocarpus laevigatus at each year of estimated age (from pooled length-frequency data for samples collected during surveys near Suva, Fiji; King (1983). The regression line fitted to data ages 4 and above has a slope of -0,66 and a coefficient of determination of 0.99.

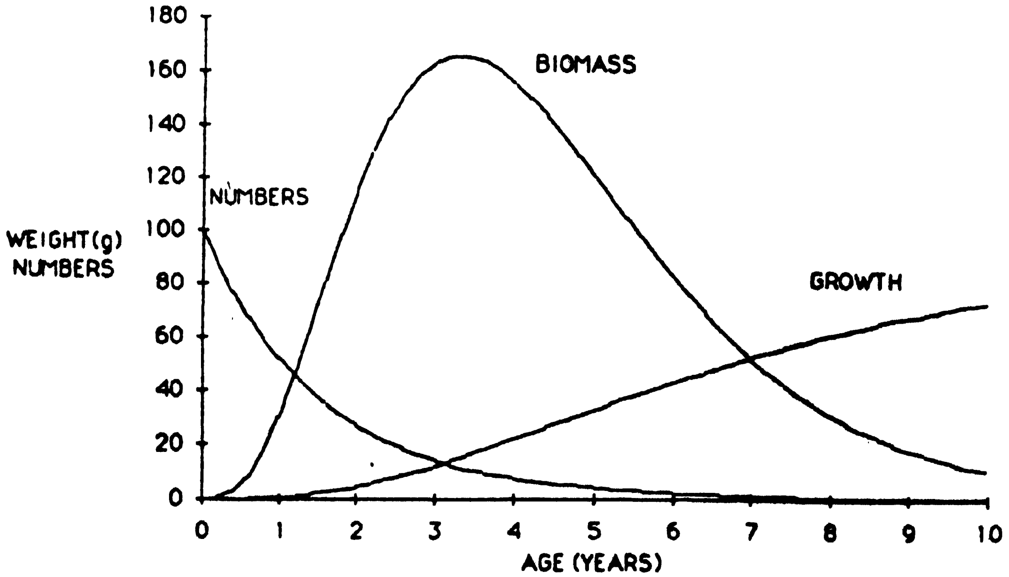


Figure 23: Estimated growth (g) survival (numbers) and resulting biomass (g) for a single recruitment of Heterocarpus laevigatus. Growth paramaters used are: $K = 0.27\ yr^{-1}$, $L_{oo} = 57$ mm

with a natural mortality rate of $M = 0.66$.

High natural mortality rates have been estimated for Heterocarpus laevigatus in Fiji and Hawaii (see Section 7) and in an intensive trapping experiment in the Marianas (Ralston, in prep.) catch rates dropped dramatically from 3.3 to 1.8 kg per trap-night over a 16 day trapping period. This decrease in catch was attributed to a decline in shrimp numbers and suggests that the species may be particularly vulnerable to even moderate trapping.

A combination of slow growth rates with high natural mortality rates suggests that the biomass (weight) of shrimps from a given recruitment is maximised at an early age. After which the available biomass rapidly decline. Figure 23 shows that the greatest biomass in an unexploited population occurs when shrimps are about 3 years old.

Yield-per-recruit model are useful in assessing the effects of two parameters, the fishing pressure (strictly the fishing mortality, F) and the age of first capture. Both of these parameters may be directly controlled by a fisheries manager, the former by regulating fishing effort and latter by setting a minimum mesh size in the traps used (see Section 2). The yield-per-recruit graphs presented in Figure 24a suggests that if the mean age of first capture is 0.5 years, yield is maximised at levels of fishing causing a fishing mortality of $F = 0.45$. If the mean age at first capture is one year the yield is maximised at $F = 0.63$. In very small mesh or covered traps shrimps less than one year of age are likely to be captured; however, in the chicken-wire traps used in Fiji the mean age at first capture was 1.2 years (see Section 2). Dailey and Ralston (in prep.) have estimated total mortality rate for Heterocarpus laevigatus in Hawaii as $Z = 1.12$ (average for both sexes); assuming a natural mortality of $M = 0.66$ results in a fishing mortality of $F = 0.46$. Depending on the selectivity of the traps used in Hawaii the stocks may be at least close to full exploitation. Figure 24b indicates that at the present Hawaiian fishing mortality of $F = 0.46$, yield-per-recruit is maximised at a mean age of first capture of about 1.8 years and that these may be some benefit in regulating mesh sizes used in the fishery.

Gulland (1983) suggested a method of obtaining an initial estimate of the potential annual yield (Y) in an unexploited stock by using the equation:

Y = 0.3 x MATURAL MORTALITY x BIOMASS

The main difficulty in using this equation is in obtaining accurate estimates of shrimp biomass (the total weight of deep-water shrimp in the population). As traps spaced at more than about 50 m apart on a bottom line appear not to compete with each other it may be assumed that a single trap attracts shrimps in from a circle with a radius of half this distance. That is, each trap samples on area of 1964 m^2. Using a natural mortality rate of $M = 0.66$ and an average catch rate of 2 kg per trap-night, the annual yield of deep-water shrimp is about 200 kg per km^2 or 690 kg per $n.mile^2$. Using the Beverton and Holt yield-per-recruit model an annual yield of 200 kg per $n.mile^2$ has been estimated for the Mariana Islands (Moffitt and Polovina, in prep.).

Such estimates of annual yield should be regarded as preliminary ones only. Nevertheless, fisheries managers in Pacific Island countries, with a knowledge of the depth-distribution and area occupied by the target species may thereby obtain figures suggesting the likely magnitude of the exploitable shrimp resource.

There has been some concern over the possible over-exploitation of deep-water stocks in Hawaii where landings exceeded 135 t in 1983. Due to the decline of the king crab fishery many large catcher/processor vessels from Alaska indicated interest in entering the Hawaiian shrimp fishery (Western Pacific Regional Fishery Management Council, 1984a) where there are no limited entry regulations. In 1985, however, it was reported that

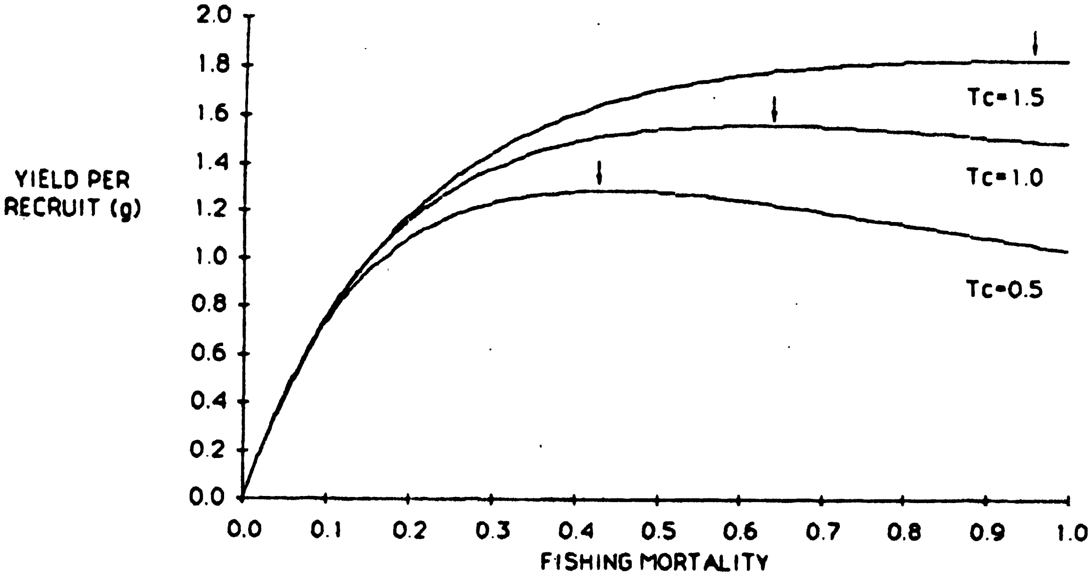


Figure 24A: *Heterocarpus laevigatus*: yield-per-recruit curves for ages at first capture (T_c) of 0.5 years (7.2 mm carapace length), 1.0 years (13.5 mm) and 1.5 years (19.0 mm). Growth and mortality parameters as used in Figure 23. Maxima are indicated by arrows.

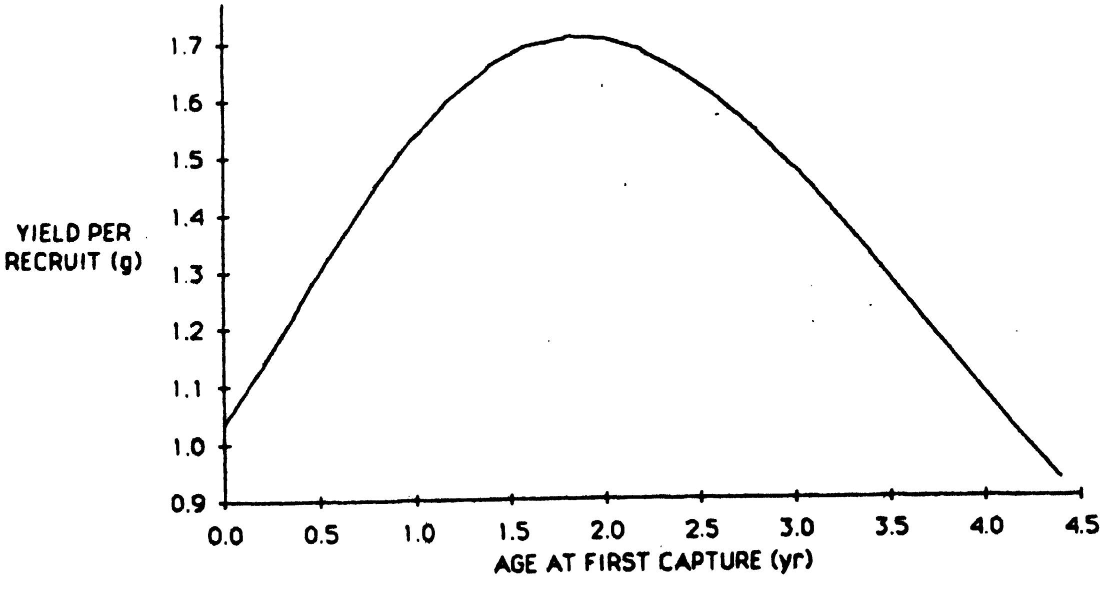


Figure 24B: *Heterocarpus laevigatus*: yield-per-recruit for different mean ages at first capture for a fishing mortality of F = 0.46. Growth and mortality parameters as used in Figure 23.

no Alaskan vessels had so far entered the Hawaiian fishery (Western Pacific Regional Fishery Management Council, 1985) and larger vessels had left the fishery for economic reasons (R. Moffitt, pers. comm. 1985). Other than in Hawaii there is little chance of such rapid development occuring in Pacific Islands. The main constraints to this development involve considerations of fishing costs and catch marketing which are addressed in the following sections.

9. COMMERCIAL OPERATIONS

In much of the survey work described in previous sections, only small numbers of traps were set from a single drop-line; small craft were used in many of these surveys. In commercial fishing, however, scales of operation may theoretically range from small village owned boats to large sophisticated vessels; in practice, both very small and very large vessels may be undesirable. Small vessels (less than 8m in length) are unable to carry a large enough number of traps for a viable commercial operation. Very large vessels besides having high initial and running costs, require repair and servicing facilities that are not available in more than a few Pacific Islands.

The 8.4 m FAO "ALIA" catamaran used in trapping surveys in both Vanuatu and Western Samoa (King, 1980, 1982) perhaps represents the smallest vessel from which a commercial operation would be practical. A catamaran has the advantage of providing a stable working platform and has a relatively large deck space for stowing the traps; the twin hulls also provide convenient storage for the large amount of rope required. Minimum equipment required is an echosounder with a working range of up to 1000 m depth and a mechanical winch capable of hauling a minimum of 15 small traps on a single drop-line.

A light displacement vessels such as the "ALIA" usually relies on outboard power with associated high running costs and low reliability, whereas a mono-hulled vessel could be powered by a light-weight diesel engine with lower running costs and higher reliability. Either vessel could be sail-assisted.

In a small boat operation it is unlikely that more than 15 small traps could be carried and handled at any one time (unless collapsible traps are used - see Section 2). Where the distance between the fishing grounds and landing area is short, a commercial operation could consist of relaying three or more strings of 15 traps out to the fishing areas, one string per trip. Subsequent operations involve hauling, emptying, rebaiting and resetting the traps without returning them to shore. With limited deck space and a small winch it takes approximately one hour to haul in, empty, rebait and reset each string of traps in a new location. At the onset of bad weather however, three trips would be required to bring all three strings to shore (alternatively, traps can be left out during bad weather providing that buoy and trap connections are chafe-free). Cannibalism, however, may reduce catches in traps left in the sea for more than the usual one night period.

Larger vessels are able to carry and set a larger number of traps. The 25 m "Sunbird" carried out short-term fishing trials during 1982 in Fiji using strings of 100 traps on each drop-line. During the "Sunbird" surveys the drop-line generally took 12 to 15 minutes to haul in before the first trap was reached; continuing at this rate a new trap was landed on deck every 15 seconds. The 15 second interval between traps was sufficient to remove the old bait, empty the catch, rebait and reset the trap over the opposite gunwhale. It was possible to haul in and reset a string of 100 traps in approximately one hour.

Relative economic aspects of two widely different types of deep-water shrimp trapping operations have been examined (King, 1982a) using the Alia 8.4 m catamaran and the 25 m vessel "Sunbird" as these vessels perhaps represent the extremes of a continuum of sizes for a commercial operation.

Economic analyses (Table 5) in Fijian dollars, were conservatively based on mean catch rates of 1.3 kg per trap and a selling price of $4 per kg. It should be pointed out that the estimated net revenue figures, ($12,733 and $154,003 for the Alia catamaran and large vessel respectively) represent general indicators of economic efficiency and not of financial success. Although the larger vessel appears to earn a much higher net return than that of the small boat, the difference between returns for every dollar invested is less substantial; returns are $1.57 for the catamaran and $1.97 for the large vessel.

Apart from economic efficiency, the financial success of any fishing operation will depend on the level of managerial mechanical, navigational and catch-handling skills of the operator. As the larger vessel operation will require a higher level of these skills, its commercial viability relative to the small boat operation may be in some doubt in developing countries.

The commercial aspects of the two-scales of operation may be viewed from the possible effect of different catch rates, fishing efforts, and price level on a vessel's net return. In both cases, the catch rates per trap and average market prices are more important than fishing effort in determining commercial success.

Large deep-water shrimp vessels in Hawaii are evolving towards the use of a smaller number of large volume traps. The large traps are reported to catch over five times the weight of the smaller traps used in the surveys described above (see Section 2). At least 17 vessels, ranging in size from 7.5 m to 39 m, were active in deep-water shrimp trapping in Hawaiian waters during 1983/84 (Western Pacific Regional Fishery Management, 1984). The smaller vessels in this size range are limited in their ability to carry and use the large trap design developed for larger vessels and may therefore be economically inefficient. At the other end of the size range, at least one company operating large vessels is reported to be in financial difficulties due to the high costs of their operation (R. Methot, pers. comm. 1985). At present, larger vessels are leaving the fishery for economic reasons (R. Moffit, pers. comm. 1985).

The above suggests that both very small and very large vessels may not be economically viable fishing units for deep-water shrimp trapping. The size of vessel is at least partly determined by marketing considerations. Although a smaller vessel may be sufficient to supply chilled fresh shrimps to local markets a larger vessel will be required to produce a frozen produce for export. Whatever the scale of operation, the viability of commercial shrimp trapping relies heavily on finding and developing markets, either locally or overseas, which return reasonable prices to fishermen.

TABLE 5: Estimated costs and returns for two types of fishing operations on deepwater shrimps based on (A) an 8.4m "Alia" catamaran and (B) a 25m tuna vessel. All figures are in Fijian dollars and are based on local (Fijian) costs, wages and prices prevailing in 1982.

	A	B
Type and size of vessel	8.4m catamaran	25m tuna vessel
Days fished per year	150	200
Costs of fully equipped vessel	$8,000	$250,000
Number of traps	45	300
Traps costs ($14.80 per trap)	$ 666	$ 4,440
Ropes, buoys, etc.	$1,200	$ 3,200
TOTAL CAPITAL OUTLAY	$9,866	$257,640
NET REVENUE PER YEAR		
Gross revenue (150/200 days fished: 1.3 kg per trap: $4 per kg)	$35,100	$312,000
Less		
Operational costs (gear replacement, bait, running costs, wages)	18,876	77,420
Fixed costs (repairs, insurance, 10% depreciation, 13% on capital)	3,487	80,577
ESTIMATED NET REVENUE PER BOAT PER YEAR	$12,733	$154,003

NOTES:

- Catch rates of 1.3kg per trap per night based on earlier survey in Fiji (Brown and King, 1979).

- Assumed that all traps and ropes replaced each year (deterioration and loss).

- Based on bait (fish, tuna heads, etc.) being available at $0.80 per kg (0.5kg used per trap per night); in practise, the supply of large quantities of bait may represent a major constraint (see Section 3).

10. HANDLING AND MARKETING

The handling of shrimps requires considerable care, more so, for example, than does the handling of finfish. Shrimps, like many other crustaceans, are regarded as luxury food items and need to be treated as such to attract maximum prices.

In samples of shrimps sent from Fiji to the CSIRO Division of Food Research in Australia, there was no evidence of enzym induced melanosis (black-spot) and "off-flavours". "Off-flavours" such as garlic-metallic taints, have caused marketing problems in other deep-water shrimps (Whitfield et al. 1981).

Because of the small deck space, catch handling on a small vessel will be limited to washing and storing the shrimps in iced sea-water. The shrimps should be stored under iced water to exclude air and reduce the possibility of enzyme-induced reactions.

The use of a larger vessel allows more sophisticated methods of shrimp preservation. Indeed, a large vessel operation may be the only method of obtaining shrimps of sufficient quality and quantity to develop export markets. Mechanically refrigerated sea-water spray (RSWS) is used on caridean (pandalid) shrimp fishing vessels on the northwest coast of America (Lee and Kolbe, 1982) and salt concentrations can be increased to 6% to produce firmer and more easily peeled shrimp. Such high salt concentrations, however, may result in excessive salt uptake in shrimps kept at temperatures above -4°C (J. Ruello, pers. comm., 1985). Large vessels also allow the on-board production of individually quick frozen (IQF) shrimps for export markets.

The major markets for shrimps are in Japan followed by the United States of America. Europe and Hong Kong. Other than European countries, these major importers border the Pacific and are, presumably, accessible to exporters in Pacific Islands. It should be noted, however, that a possible glut is predicted by 1990, mainly due to the increased production of penaeid shrimps from aquaculture (van Eys, 1985). The total production from aquaculture of shrimp from the Indo-Pacific is predicted to increase from about 50,000 t. to over 140,000 t. by 1990. Of this total, aquaculture production from Pacific Islands is likely to be 100 t.

In the face of this predicted increase in production and market oversupply, the stability of Pacific Island deepwater shrimp fisheries may depend on:

1. The ability to fulfil requirements for particular species of shrimps. The huge predicted production referred to above is likely to be based on a single species of penaeid shrimp, Penaeus monodon. In Japan, a special market for caridean shrimps of the family Pandalidae, collectively known as ama-ebi, is likely to persist. Pandalid shrimp, with their sweet taste and "sticky" texture, are usually eaten raw in Japan.

2. The ability to develop domestic markets. The potential for import substitution exists in Pacific Islands where there are local centres of population or tourism. In Fiji, during 1984, for example, F$150,000 worth of shrimp were imported (Fisheries Division, Annual Report, 1979) mainly for the restaurant and hotel trade.

From marketing experience in Hawaii (Oishi, 1983), deep-water shrimps were found to be acceptable in four different forms. These are presented below in order of importance in termes of demand:

1. whole individually quick-frozen (IQF) shrimps
2. fresh (iced) whole shrimps
3. shrimp tails - (meat only)
4. shrimp tails - (with shell)

Large deep-water shrimp, individually quick-frozen and presented in 2kg "shatter-packs" were found to be most acceptable on the Japanese market (Western Pacific Regional Fishery Management Council, 1984). To gain continued acceptance on the Japanese ama-ebi market, shrimps must be well-presented with no missing appendages. A Tokyo-based buyer has expressed interest in importing approximately 18,000 kg of deep-water shrimp at a 1981 price of US$4-95 per kg, f.o.b. Hawaii (Oishi, 1983).

Large whole (fresh, chilled) shrimp appear most acceptable on local markets, particularly where demand from restaurants and tourist hotels is high. Initial marketing trials in Fiji suggested that deep-water shrimps were less acceptable than imported penaeid shrimps and ex-vessel prices were about F$4 per kg (King, 1982a). Market prices in New Caledonia in 1981 were about F$6.50 per kg. Ex-vessel prices during 1981 for deep-water shrimps marketed locally in Hawaii varied greatly with shrimp size as shown below (from Oishi, 1983).

Shrimp size	Number per kg	Price (US $)
Small	> 45	$1.10 to 2.86
Medium	25-45	$4.40 to 6.60
Large	< 25	$7.70 to 11.00

A processing company based in Hawaii estimated that up to 1.3 tonnes per week could be absorbed by local markets without depressing the prices given above (Oishi, 1983). It should be noted however, that other Pacific Islands, without large populations and tourist industries, may have much smaller local demands for deep-water shrimps.

The low meat recovery rate of deep-water shrimps makes the marketing of shrimp tails (abdomen) less attractive commercially. Tail flesh generally accounts for about 20 percent of the total shrimp weight (see Figure 25). In spite of this, a processor in Hawaii maintains that small shrimp could profitably be marketed in this way provided that a large continuing supply is assured (Oishi, 1983). The United States of America is likely to be the most important market for frozen shrimp tails. In the Heterocarpus reedi fishery in Chile, shrimps are cooked and rapidly cooled before being peeled. In the peeling process, the muscles under the cephalothorax are left attached to the tail meat to increase the recovery rate. The meat may then be frozen in slabs at -30°C and glazed for protection (Weinborn, 1982).

In Pacific Islands in general, only two of the previously discussed marketing methods are likely to be feasible. Firstly, the development of local markets for fresh, iced shrimps may be possible near centres of tourism and large populations. If fresh shrimps are supplied through retail outlets, retailers must be made aware of proper handling procedures. A situation where many of the handling and marketing problems would be reduced, is one in which a small vessel operates in conjunction with a large hotel or tourist resort. Assuming that suitable depths occur within a few miles of the resort (this is true for many resorts in Fiji, for example) freshly caught shrimps could be brought directly in to the resort. Both the fishing operation itself and the quality of local product would, no doubt, provide additional interest to resort guests beyond the actual value of the shrimps caught.

Secondly, the development of overseas markets for IQF shrimps may be possible if local facilities are sufficient to support the necessarily larger and more sophisticated vessels required for this scale of operation.

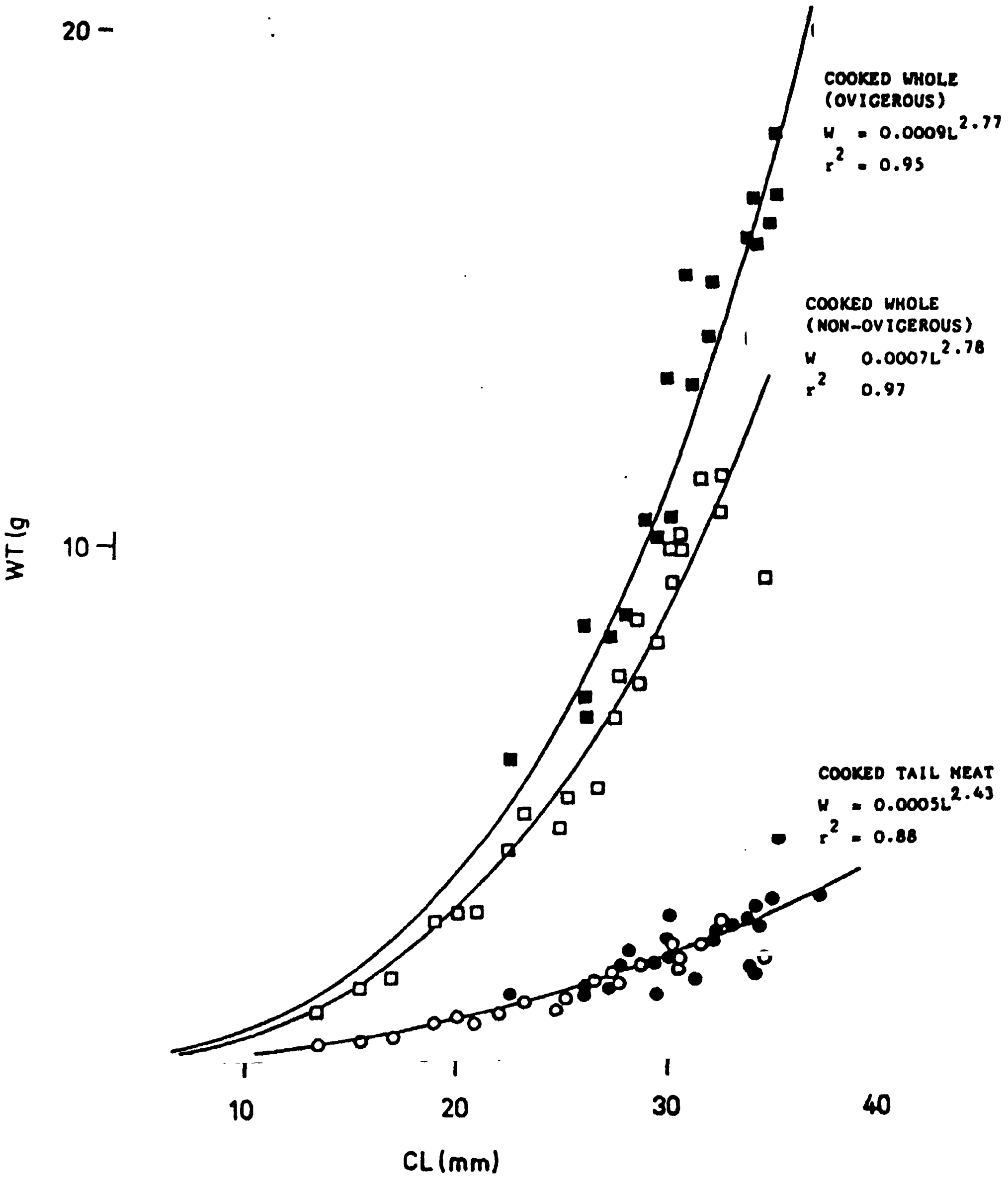


Figure 25: Heterocarpus sibogae: relation of cooked whole weight (squares) and cooked "tail" meat weight (circles) to carapace length (mm). Non-ovigerous individuals indicated by open points and ovigerous individuals by solid points. All shrimps were stored frozen then individually cooked for 1 minute in a boiling 6% salt solution.

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NO: 11203